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Now that the standard high speed steel analyses are under priority, and for civilian uses toolsteels must be accepted wherein molybdenum replaces much of the tungsten, the advantages and shortcomings of the various types should be well in mind

Molybdenum High Speed Steels

"Mr. White and the speaker stated in our patent that molybdenum can be substituted for tungsten in modern high speed steels and that one part of molybdenum will produce approximately the same effect as two parts of tungsten." These words were not spoken in this decade nor the last but by F. W. Taylor in his famed address on "The Art of Cutting Metals" in December 1906 to the American Society of Mechanical Engineers. Other substantial evidence that the substitution of molybdenum for tungsten in high speed steels was well known at that time is the fact that the Sanderson Steel Co. marketed a molybdenum high speed steel under the trade name of "Mo.S.H." (molybdenum self-hardening) in 1898. Its chemistry differed considerably from modern high speed steels, but the significant elements were molybdenum and chromium and not tungsten and chromium. Why then was the use and further development of this type of steel discontinued? The problem of decarburization (still objectionable in the higher molybdenum types even though today the problem is solvable) was no doubt the controlling reason. Furthermore, at that time there was neither strategic nor economic advantage.

A new interest in molybdenum high speed steel started in 1927 when realization of the large potential American production of molybdenum actuated the investigations of the Watertown Arsenal. These investigations covering a period of several years culminated in their Experimental Report No. 359, issued under date of June 30, 1930. The Watertown Arsenal report recommended a steel containing 0.70% carbon, 3.50% chromium, 9.50% molybdenum and 1.30% vanadium. An important contribution of this report was the evidence that decarburization in manufacture and heat treatment could be prevented by covering the steel with a coating of borax. Since that time developments have been along such orthodox lines that one cynic stated that the only recent discoveries in this field were that some compositions could be patented!

For many years, therefore, it has been generally recognized that the primary difficulty with molybdenum high speed steel was its propensity to decarburization. Changes in manufacturing technique, developments in heat treating procedure and equipment, and chemical modifications have all focused on eliminating or substantially reducing the loss of surface carbon during heating for forging and hardening. In process of manufacture it has been found expedient to coat ingots and billets with borax or

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and Robert S. Rose
Sales Metallurgist
Vanadium-Alloys Steel Co.

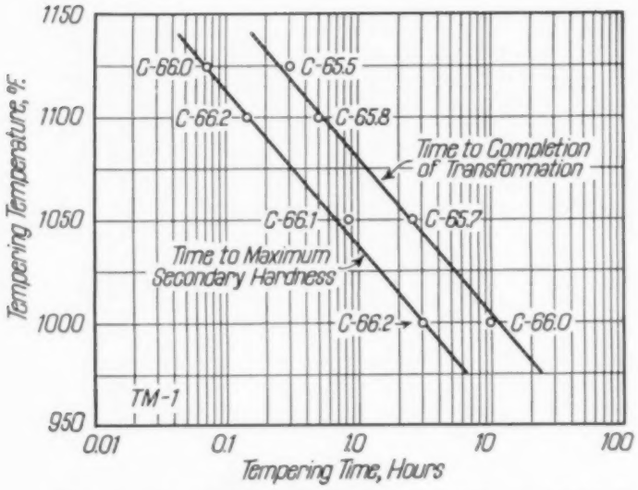


Fig. 1 — Steel TM-1, Quenched in Oil From 2250° F. Holding time to obtain maximum secondary hardness and to obtain complete transformation on subsequent cooling from the temperature shown. (Figures next to curves are Rockwell "C" hardnesses at indicated points)

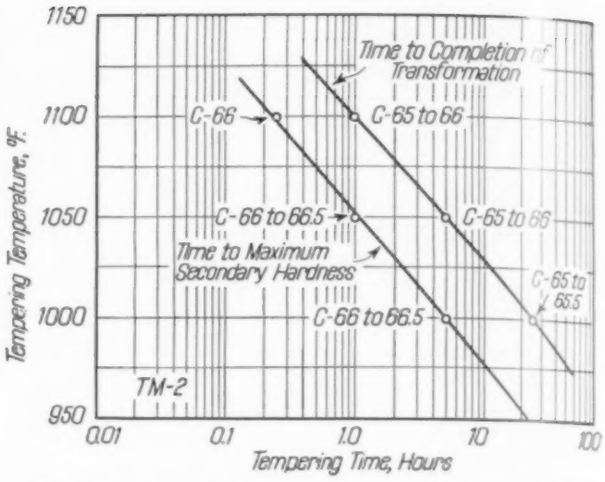


Fig. 2 — Steel TM-2, Quenched in Oil from 2225° F. Holding time to obtain maximum secondary hardness and to obtain complete transformation on subsequent cooling from the temperature shown. (Figures next to curves are Rockwell "C" hardnesses at indicated points)

copper paint. Frequently it has also been necessary to remove the entire surface from billets before final rolling. Improved treating methods have resulted from experimental work with various types of coatings, salt baths, and controlled atmosphere furnaces. The chemical composition has been modified by replacing a small amount of the carbon content with boron and the addition of copper. The boron replacement, while conducive to less decarburization, embrittles the steel in forging to such a degree that it can be used only in a limited amount. Copper also helps to prevent the decarburization caused by molybdenum but is insufficient to overcome the entire difficulty.

All the molybdenum high speed steels can be heat treated without decarburization by the use of borax coatings, appropriate salt baths, or in furnaces capable of producing an atmosphere containing 20% CO or above. Carburization in varying degrees and depths may occur under the latter condition. It is not possible to claim categorically that decarburization will not occur on the higher molybdenum types (above 7%) in the most frequently encountered high heat furnaces whose atmospheres are limited to about 15% CO. Under these conditions, best results will generally be obtained by the use of a low (about 1200° F.) oxidizing preheat.

X-ray diffraction analysis shows that when molybdenum is added to high speed steel it replaces the tungsten atom in the double carbide. X-ray patterns with the No. 2 Phragmen camera of tempered specimens of the 18% tungsten type, Type TM-2, and Type TM-3, show three phases common to all three steels — *(a)* retained austenite, *(b)* primary martensite and *(c)* double carbide.

Lattice parameters of the carbide phase are shown in Table III. It is significant to note that the double carbide has the same parameter in all three types despite the fact that TM-3 has no tungsten and 18-4-1 has no molybdenum. It is probable, since the elements tungsten and molybdenum have almost equal atomic radii, that the carbide phase can dissolve (by iso-

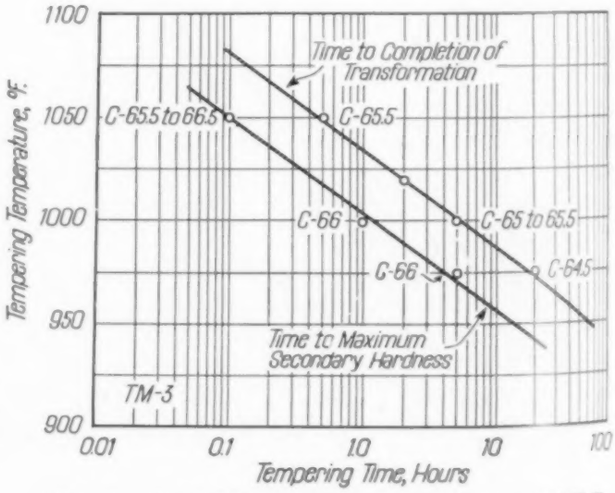


Fig. 3 — Steel TM-3, Quenched in Oil From 2225° F. Holding time to obtain maximum secondary hardness and to obtain complete transformation on subsequent cooling from the temperature shown. (Figures next to curves are Rockwell "C" hardnesses at indicated points)

Table I — Standard Compositions

Type	C	W	Mo	Cr	V
T1-1	0.80	5.0 to 6.0	3.5 to 5.5	4.0	1.40 to 1.75
M-1	0.83	...	7.5 to 8.5	4.0	2.00
M-2	0.80	1.5	8.0 to 9.0	4.0	1.00

morphous replacement) either or both kinds of atoms in varying proportion. Thus it may be expected that the effect on the properties and reactions of the high speed steel compositions is linear or proportional to the addition or replacement of either element.

That a substantial replacement of molybdenum with tungsten increases the stability of the retained austenite is clearly seen by comparing the chart of TM-3 with that of TM-2 (Fig. 3 and Fig. 2 respectively). The former contains 8% molybdenum with no tungsten, while in the latter 3% of the molybdenum has been replaced with 5.65% tungsten. For complete austenite transformation in two hours, a temperature of 1020° F. is required with TM-3 and 1080° F. with TM-2. Moreover, the time to reach maximum secondary hardness at 1050° F. is 0.1 hr. with TM-3 and 1 hr. with TM-2. (Similar data for three other steels are given in Fig. 1, 4 and 5.)

The past several years have seen the modification of the standard high speed types with higher carbon and vanadium contents. This trend has reached its maximum to date in Type TM-2 and results in abrasion resistance several times that of 0.70% carbon 18-4-1. The increase in cutting efficiency with higher carbon and vanadium is now well established, but the applications must be selected with some caution due to the accompanying increase in grinding difficulty.

Table II — Compositions That Are Obtainable

Type	C	W	Mo	Cr	V	Co	B
TM-1	0.83	5.0 to 6.0	3.5 to 5.5	4.0	1.40 to 1.75	...	...
TM-2	1.27	5.0 to 6.0	4.0 to 5.0	4.5	4.00	...	...
TM-3	1.25	...	8.0	4.5	4.00	...	...
TM-4	0.80	6.0	6.0	4.0	1.50	6.0	...
M-1	0.83	...	7.5 to 8.5	4.0	2.00	...	...
M-2	0.80	1.5	9.0	4.0	1.00	...	...
M-3	0.83	1.5	9.0	4.0	2.00	...	...
M-4	0.80	1.5	8.0	4.0	1.00	5.0	...
M-5	0.80	1.5	6.5	4.0	2.00	5.0	...
M-6	0.80	1.5	8.0	4.0	2.00	8.0	...
M-7	0.60	...	8.0	4.5	1.00	2.5	0.25
M-8	0.60	...	8.0	4.5	1.50	8.0	0.25

Recent modifications in molybdenum high speed steel compositions have followed the lines of good logic. The reasoning has been somewhat in this vein: "Let's admit the decarburization problems encountered with high molybdenum high speed steels. Therefore, why not decrease

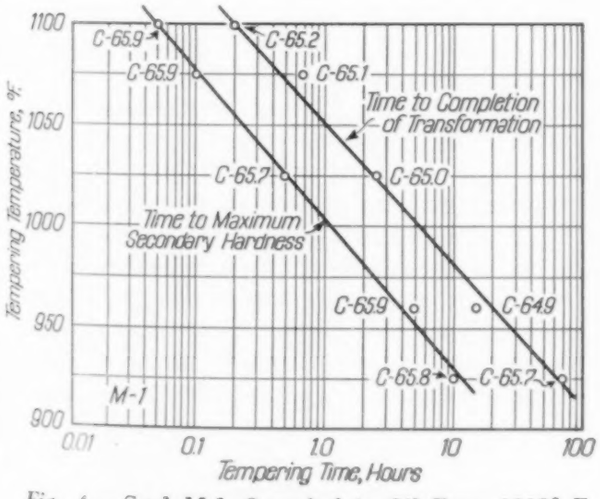


Fig. 4 — Steel M-1, Quenched in Oil From 2225° F. Holding time to obtain maximum secondary hardness and to obtain complete transformation on subsequent cooling from the temperature shown. (Figures next to curves are Rockwell "C" hardnesses at indicated points)

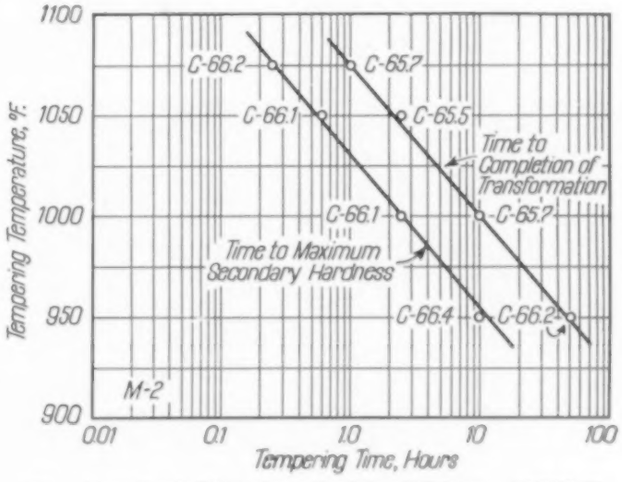
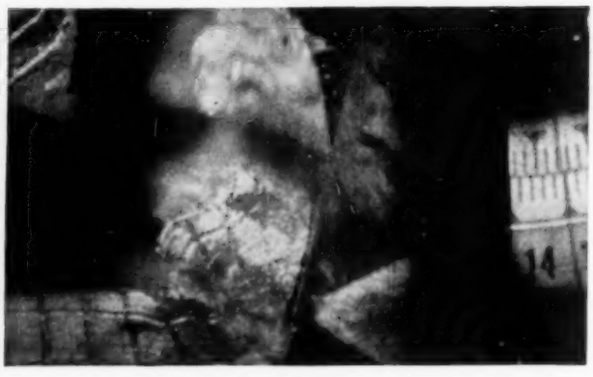


Fig. 5 — Steel M-2, Quenched in Oil From 2225° F. Holding time to obtain maximum secondary hardness and to obtain complete transformation on subsequent cooling from the temperature shown. (Figures next to curves are Rockwell "C" hardnesses at indicated points)



General Electric's Researchers Recently Turned the Ultra-High Speed Camera on the Machining Operation. This shows the action of a planer tool on cast iron. Markings on 1/32-in. grid show extensive crushing ahead of tool. Note chips flying off

Table III — Lattice Parameters*

Steel Tested		Carbide, Face Centered Cubic	Lattice Parameter
Type	Nature		
TM-2	W-Mo	$(Fe,W,Mo)_6C$	11.05 A. u.
TM-3	Mo	$(Fe,Mo)_6C$	11.05 A. u.
18-4-1	W	$(Fe,W)_6C$	11.057 A. u.

*Data are from correspondence with Cohen and Lament of Massachusetts Institute of Technology.

the molybdenum to where they virtually disappear and add sufficient tungsten to obtain the necessary equivalency?" Thus the introduction of the so-called 6-6, 6-5 and 5-4 types.

When the molybdenum content is reduced to under about 5.5% and replaced with between 5 and 6% tungsten, the decarburization susceptibility is almost altogether eliminated in both manufacture and heat treatment. High speed steels of this composition (Type TM-1) can be successfully heat treated without coating for well-nigh all types of tools in any type of heat treating equipment suitable for 18-4-1. Even in obsolete gas-fired and oil-fired furnaces without atmospheric control, freedom from decarburization can be obtained by the use of an oxidizing preheat and a so-called slightly reducing superheat. The manufacture of high speed steels of this type is no more involved than the 18% tungsten type, and Damocles' sword of decarburization does not exist!

It has been difficult for consumers to comprehend the exact nature of molybdenum high speed steels, not only due to the many conflicting statements that have been made, but also due to the patent situation. Fortunately this has been considerably clarified by the procedure of the Climax Molybdenum Co., which developed the 6-6 type, in releasing the data to all makers of high speed steel and not applying for a patent. Also, the Allegheny Ludlum Steel Corp. has released its patent on the 5-4 type, and the Crucible Steel Co. of America and the Vanadium-Alloys Steel Co. have released their patents on the molybdenum-vanadium types. Thus the patent on the M-2 type is the only one on a molybdenum high speed steel of considerable production not available to producers and consumers without payment of royalty.

That the tungsten-molybdenum and the molybdenum high speed steel can be satisfactorily used for almost all types of cutting tools is now well established. As to whether certain types are a little better or a little worse for specific applications is one of endless discus-

sion, since the variables involved in most cutting operations are so complicated that it is often difficult to obtain reproducible results with a single type of high speed steel. It is significant that over a long period of years the 18-4-1 type has most closely approached this status of reproducibility or uniformity of results, which fact likely accounts for its outstanding popularity. In this respect the tungsten-molybdenum steels of the TM-1 type containing nearly equal amounts of tungsten and molybdenum more nearly resemble 18-4-1.

One of the requirements of all high speed steels is red hardness. This term implies cutting hardness *at red heat*, and is distinct from hardness at room temperature that may obtain after exposure to the red heat. A tool to be successful for a specific application must be hard at the temperature developed by the application.

Thus, while other factors are known to be involved, it is not surprising that a good approximation of cutting efficiency can be obtained from measurements of hardness at elevated temperatures. Both E. G. HERBERT in his 1930 "Report on Hot Hardness Characteristics of Some Modern Tool Steels and Alloys" to the British Institution of Mechanical Engineers, and O. W. BOSTON in researches at the University of Michigan, by using the cutting tool and the metal being machined as two elements of thermocouple, have shown that temperatures of 1100 to 1250° F. obtain at the point of contact with moderate feeds and speeds. The temperature of 1200° F. has been selected for hot hardness comparisons in Table IV between the three most popular molybdenum high speed steels. The hot hardness of 18-4-1 and 18-4-2 from Harder and Grove's work ("Hot Hardness of High Speed Steels and Related Alloys," Technical Publication No. 497, 1933, of the American Institute of Mining and Metallurgical Engineers) is included for further comparison.

Table IV — Hardness at 1200° F.

TYPE	QUENCHED FROM, °F.	DRAW		HARDNESS	
		°F.	TIME	AT 70° F.★	AT 1200° F.†
TM-1	2260	1050	2.5 hr.	65	342
M-1	2220	1020	2.5 hr.	64.5	313
M-2	2220	1020	2.5 hr.	65	308
18-4-1	2350	1075	2.0 hr.	64.2	312
18-4-2	2350	1075	2.0 hr.	65	344

★Rockwell C scale. †On Brinell scale of hardness numbers, but obtained by method of mutual indentation.

It is apparent that Types M-1, M-2 and 18-4-1 have nearly identical hot hardness values; variations are certainly within the experimental error of the method. It is equally apparent that the hot hardness of Type TM-1 is considerably greater than that of the other two molybdenum types and compares favorably with 18-4-2. The probable reason for the higher hardness of TM-1 is the combination of an appreciable tungsten content with high vanadium.

Table V — Thermal Conductivity in Watts/cm.²/cm./°C.

TYPE	150° C.	200° C.	300° C.	400° C.	500° C.	550° C.
M-1	0.203	0.210	0.223	0.236	0.249	0.256
18-4-1	0.209	0.214	0.226	0.239	0.251	0.258

There is little difference between the thermal conductivity of an 18% tungsten high speed steel and a tungsten-free, 9% molybdenum high speed steel. Some justifiable significance is attached to this property since a cutting tool with high conductivity would more quickly dissipate the generated heat and thus reduce the temperature to which the tool is exposed. Table V shows the thermal conductivity of heat treated 18-4-1 and Type M-1 over a temperature range of 400° C. These values were determined by the method developed by the National Bureau of Standards and described in Research Papers No. 668 and 669. It is evident that the two types of steels have approximately the same conductivity in the range observed and that the conductivity increases with increase in temperature.

The statistics on the production and importation of tungsten for the year 1941 do not indicate even a scarcity of tungsten this year for 18% tungsten high speed steel. Should the worst fears be realized and all importations of tungsten stopped, there is still ample domestic tungsten production to satisfy the requirements for production of high speed steel in 1942 and 1943 of steel of the type of TM-1. A further factor of safety exists for ample tungsten for this type of steel when it is realized from 65 to 75% of the scrap of the huge production of the 18% tungsten steel of the present year will return to the producer for remelting. It is diffi-

cult to make estimates of the current production of the different types of molybdenum high speed steels, as this information has not been compiled directly from the producers. The molybdenum-vanadium type, M-1, has increased greatly in production during the present year, while Type TM-1 is increasing in production at such a rapid rate that it appears it will be produced by early 1942 in amounts larger than the make of all other types of molybdenum high speed steels combined.

Table I shows the three primary types of molybdenum high speed steel which are in general production. Table II shows the many variations in composition of high speed steels which are being commercially produced, and Table VI shows the suggested substitutional types for the most widely used types of tungsten steels.

Table VI — Suggested Substitutes

18-4-1	TM-1
	M-1
	M-2
18-4-2	TM-1
	TM-2
	M-1
	M-3
	M-7
18-4-1 + 5 Co	TM-2
	TM-3
	TM-4
18-4-2 + 8 Co	M-4
18-4-3 + 12 Co	M-5
	M-6
	M-8

Detailed recommendations for the heat treatment of the steels listed in Table I will soon be issued by the O.P.M. and for that reason are being omitted from the text. [Editor's Note: These are printed on page 307 of this issue.]

Transformation-Time Charts

It probably will be of interest to the readers to have available for reference the charts on tempering (Fig. 1 to 5). These charts have been prepared by using the quenching temperature indicated and then tempering at the temperatures shown on the left for the tempering time shown on a logarithmic scale in hours at the bottom. These charts show the time necessary to hold the specimen to obtain maximum secondary hardness, as well as the time to obtain complete transformation, using different tempering temperatures.

British Steel Supplies

In view of the recent announcement from the Office of Production Management that American steel would be placed under full priorities, the following official statement from the British Steel Controller concerning the situation in Great Britain will be of interest. It is quoted from *The Engineer*, issue of July 11, 1941, p. 27.

(1) *Q.* — Are home and imported supplies of iron ore and scrap adequate?

A. — The answer is "Yes". The Iron and Steel Control has been laying aside considerable reserves of home and imported supplies of raw materials and it many be said that with regard to both iron ore and scrap the position is very satisfactory.

(2) *Q.* — Are supplies of finished steel adequate, especially for naval and mercantile uses?

A. — The total steel available is very much more than this country has ever had in its history. One must appreciate that steel is probably the most important raw material necessary for the war effort and that the uses of steel change very considerably in a war requirement compared with peacetime; therefore, in making a proper use of steel for war some of the capacity required for peacetime operations may today find itself not fully employed; but to employ such capacity simply for the use of the productive capacity would be neither economical nor desirable.

To build a transport airplane or heavy bomber at least 5 tons of high grade alloy steels are required. This, perhaps better than any other illustration, reveals the wartime importance of alloy steels, the production of which in this country is now vastly in excess of pre-war figures and sufficient to meet the heavy demands made upon the steel industry by arms factories engaged in every type of armament production. Before the war the British steel industry was designed to meet peace requirements, and it was feared that for a time at least it might be difficult to supply all essential demands for alloy steels. Fortunately, the change-over was facilitated by the far-seeing increase in electric furnace and openhearth capacity laid down just after the outbreak of war.

The industry's performance as a whole is the more notable when it is remembered that many of the essential raw materials were formerly imported from sources now under Axis control. After the fall of France, the industry's raw material experts brought into operation alternative foreign sources of raw material (*Cont. on p. 370*)

Mr. Williams presented a number of lectures before the Tri-City Chapter of last winter on "Selection of Steel for Manufacturing Purposes". Excerpts from these have formed the basis of a series of articles, concluded in this issue, to make way for the publication of the entire text in book form

Fabrication Considerations When Selecting a Steel

HAVING CONSIDERED in this series of articles starting seven months ago the more common physical properties of steels, some of their metallurgical characteristics and the heat treatment facilities existing in the shop that affect the selection of steel for manufacturing purposes, let us now turn briefly to the fabrication operations and how the available steels may react to them, either to help or hinder.

Forgeability is first, at least in the sequence of operations. There is not much we can do about it. Action of steel at forging temperatures does not have any direct relation to its useful properties at room temperature. Therefore, we have to specify with regard to ultimate properties required in the part and let forgeability take care of itself. Of course, low carbon steel forges more readily than high carbon steel; the alloy steels are sometimes harder to forge than a plain steel of the same carbon content, some of the alloy steels have adherent scale and some scale is more abrasive than others. In hard steels, if they require any subsequent cold work, it may be necessary to anneal the blanks to get any kind of life on the dies.

Practically the only printed data on the forgeability of steels that I know about are contained in O. W. ELLIS's paper in METAL PROGRESS for September 1932. Some of his results are given in the first diagram. Alloys generally decrease the forgeability of steels with the same carbon content, but this action is shown mostly at temperatures near the finish of the operation. The plasticity of the steels, as tested by ELLIS, is all at about the same value at 2200° F. where forging begins.

There is a well-established practical conclusion that coarse-grained steels (that is, steels which have a large austenitic grain size after carburizing at 1700° F.) are more readily forgeable and easier on the dies than fine-grained steels. It is to be presumed that *all* steels will get coarse grained at forging temperatures (2000° F. and above) and the associated embrittlement has been counteracted since pre-historic times by continuing the forging down to dull red heat (to break up the grains mechanically) or to refine the grain metallurgically by a subsequent heat treatment, like normalizing or a quench and draw. Nevertheless, it is good practice to get coarse-grained steels for forging — if the subsequent forging and heat treating practices will insure proper refinement, or if the expected service does not require the added toughness of a fine-grained structure.

Formability — For cold forming purposes, the *cold formability* of steel is some function of yield strength combined with its ductility.

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Deformation only starts in the plastic range above the yield point of the steel. Work hardening also sets in here, progressively stiffening the metal — particularly in the low carbon, plastic steels. (It is quite interesting in this connection to discover that you can sometimes make deep draws in one rapid operation which you couldn't possibly do leisurely in two or three.)

Requirements for cold heading stock which must also be machined to make parts like bolts are difficult to meet because they involve mutually contradictory properties. For best action in the cold heading dies the metal should be plastic and stiffen as little as possible by cold work; for best action when thread cutting, the chips should cold work rapidly and become brittle enough to break. Obviously some compromise is necessary.

Sheet for Deep Drawing

Sheet metal for deep drawing is produced every year by the millions of tons. Some of it must withstand excessively severe deformation, as a front fender for a 1941 automobile. Practically all of this sheet is bought on the basis that the steel maker will take it back if it does not perform satisfactorily in the dies. That means that on important jobs the steel mill metallurgist and the production engineers in the sheet metal shops work closely together on the preliminaries so the metal delivered will withstand the work laid out for it.

An added complication is that ordinary low carbon openhearth steel sheet will age somewhat during the time elapsed between finish rolling and straightening, and delivery to the customer's press. That is to say, the sheet becomes considerably harder, stronger, and less ductile. The cause of aging is still hypothetical — there may be more than one thing responsible, but some steel companies are prepared to furnish "non-aging" sheet, for a premium. Aged sheet can be restored temporarily to its original ductility by putting it through a roller leveler.

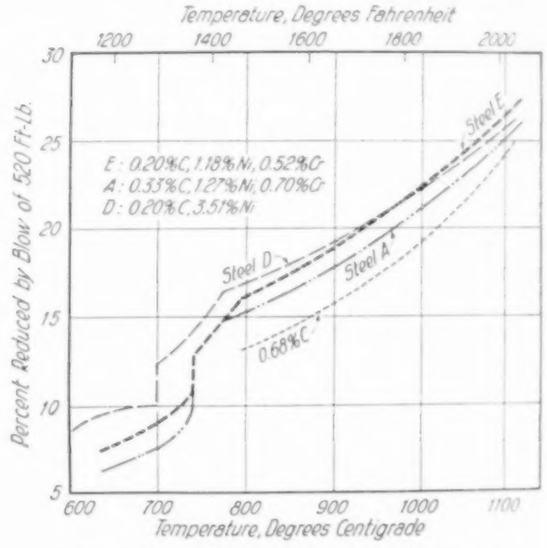
In some instances brittle breaks in equipment (especially in cold climates) have occurred which apparently are due to the aging of stress-carrying stampings of thin plate. One remedy would be to use non-aging steel.

Surface of the steel is highly important for any drawing operation for two reasons:

1. For proper slippage through the dies.
2. Because we are putting a terrific amount of stress and of deformation at single points, and stress raisers are going to cause trouble there. For example, if you try to deep draw around a punched hole which is rough inside, the part may split. If you ream and then deep draw, you will be more successful.

Internal stresses are built up during cold work. Everyday evidence of this is the springback as the work leaves the forming operation, and the warpage in any subsequent heat treatment. I have seen pieces that will warp severely while being heated, and yet the heat treater was expected to put them through and bring them out better than they were in the first place.

Flame Cutting — Oxygen or flame cutting is becoming an increasingly important tool, particularly in intermediate production quantities, and on very heavy stock in small production quantities. The action of the cutting flame depends on heating of the steel to its kindling temperature and then supplying enough pure oxygen to let it burn and generate its own heat,



Low Carbon, Nickel-Chromium Steels Are Just About as Plastic at High Temperatures Under a Single 520-Ft-Lb. Blow as Plain Steels of Similar Carbon Content

then guiding the stream of oxygen and the flame along the path to be cut. This operation will require consideration of one factor especially, and that is hardenability. The steel surface of the kerf is heated to kindling temperature and cooled suddenly by radiation into the cold mass of metal underneath. If it hardens considerably it may develop tiny surface cracks and will have low ductility. Consequently, it may be necessary either to use steel which will not harden under those conditions, to preheat the

piece, or to anneal afterwards. Both of these last-mentioned operations can frequently be done by auxiliary flames just ahead of or just behind the cutting flame. As a matter of interest, sheared surfaces in mild carbon steel (structural grade) are much more apt to start cracks under high stress than flame-cut surfaces.

Welding is another factor that influences selection of material. Fundamentally, hardenability is the biggest single factor that influences selection of materials to be welded. In fact, they are the very antithesis of each other in the sense that the steel that has least hardenability usually has the best weldability.

The sketch below indicates the temperature distribution in a typical fusion weld. The welder starts out with a cold mass of steel; he brings the edges up to a temperature in the neighborhood of 3000° F., possibly more, and then it cools suddenly. We have a radical drop in temperature in the heat affected zone; if the work is rapidly done — as is the production man's ideal — the previously molten portion is cooled so rapidly as almost to constitute a quench. Since the gas weld (other things being equal) is slower than the arc weld, there is more time for the heat to go back into the base metal; that means that the cooling rate is going to be more gradual because the heat is spread out over a larger volume; there is more hot metal, and consequently the quenching effect of the cold mass will be less than in a section welded by the metallic arc.

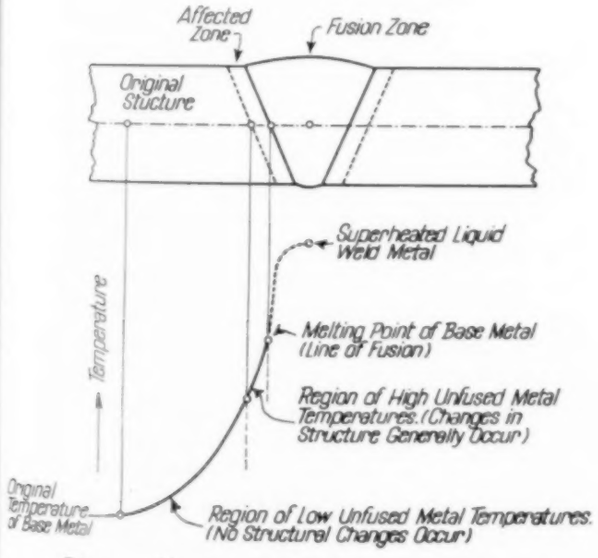

Affected Zone
Fusion Zone
Original Stucture
Superheated Liquid Weld Metal
Temperature
Melting Point of Base Metal (Line of Fusion)
Region of High Unfused Metal Temperatures. (Changes in Structure Generally Occur)
Original Temperature of Base Metal
Region of Low Unfused Metal Temperatures. (No Structural Changes Occur)

Diagram Showing the Maximum Temperatures Attained at and Alongside a Typical Fusion Weld in Steel. (Hodge and Miller, in "Welding Handbook" of American Welding Society)

The hardening due to arc welding various common steels is summarized in the diagram on page 292. A 0.17% carbon steel, for example, will show an as-rolled hardness of about 120 (the lower dotted line), but hardens to 150 to 180 in the hardest area after welding. (The tops and bottoms of the blocks represent the variation in hardness due to speed of arc travel; the highest hardness is obtained by the fastest welding.) A 0.53% carbon steel with 200 Brinell as rolled shows 220 to 430 in a maximum heat affected zone. Here we see clearly the effect of hardenability — even more clearly is this evident when we notice S.A.E. 4150, going from 290 to above 600 Brinell.

X-4130 (1% Cr, 0.20% Mo) is quite widely used for aircraft tubing and is generally gas welded. It is not shown on the diagram. Aircraft fittings need considerable strength (hardenability) to carry the stresses, but need little hardenability to be readily weldable — which is a nice trick if you can do it. A further requirement is that the heat affected or "annealed" zone alongside the "quenched" edge must not be softened so that it is much weaker than it is elsewhere. A mildly air hardening steel which tempers sluggishly and is of considerable strength and impact resistance in thin-walled tubing or thin plate — that's X-4130. In 1×0.065-in. tubing, whose original hardness is Rockwell B-100, the center of either an oxy-acetylene or arc welded butt is not hardened at all, and the softest annealed zone alongside is no softer than B-90.

In recent years there have been a number of so-called low alloy, high strength structural steels proposed, particularly for railroad car construction. These have considerably higher yield strengths than the regular structural steels, and all must be adaptable to welding — that is, show a high strength, high yield and good ductility both before and after welding. This can only be done by intelligent selection of alloying elements to strengthen the steel rather than give it hardenability. Several of these alloys are noted on the diagram on the next page.

About the maximum carbon in commercial carbon steel safe for welding without preheating or subsequent heat treatment is 0.30%. Higher carbon steels are welded every day, but usually only with proper preheating.

Machinability — Since so much money is spent in machine shops it is only natural that a good deal of attention has been given to the relative machinability of the various alloy steels.

Machinability implies several things. To production men, it generally means the removing of metal at the fastest rate with the best possible finish and with the longest possible tool life. The requirements for *maximum* machinability are those we cannot possibly have in steel. A weak, brittle material free from any abrasive particles would be the best to machine. That combination we can't have in sound steel, for it is an inherent characteristic of this alloy that when we get low tensile strength we have high ductility, not brittleness.

In general practice, a Brinell hardness in the neighborhood of 180 is pretty good for the machine shop, especially if this hardness is combined with poor ductility, although, given the will to do it and the tools, we can machine materials that are heat treated to a surprisingly high hardness. We can frequently help the machinability of a given steel by heat treatment; that is, we can normalize it if it is a low carbon material, in order to bring up the hardness to something approximating 180 and likewise reduce the ductility. We may even quench 1015 or 1020 steels to bring up the hardness.

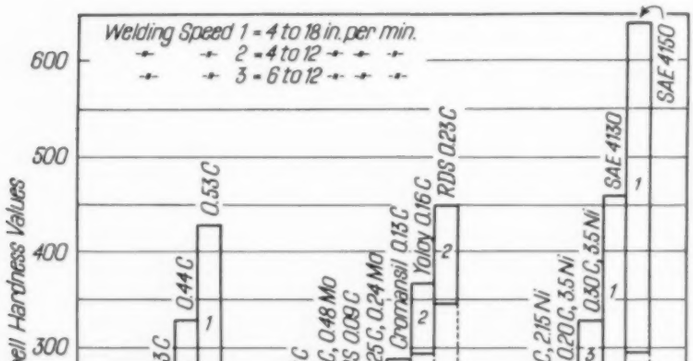
A comprehensive list of steels, ranked as to their machinability, is given in the data sheet published in METAL PROGRESS last January. A table given on page 899 of Metals Handbook summarizes the ratings for several of these steels in the cold-drawn and in the annealed condition. There are so many things that influence machining that the application of such tables is not very satisfactory.

Machinability of cold-drawn screw stock is taken as 100%. The improved X-1112 will rate 140%. Let's realize the implications of that by comparing it with the value for 1020. S.A.E. 1020 is similar in carbon and manganese to the 1112 but has lower sulphur and low phosphorus, and it will have a machinability somewhere in the neighborhood of 65%. The considerably higher percentage of sulphur and phosphorus makes 1112 brittle. Sulphur does this in a fortunate way — the sulphide particles distributed throughout the steel are not especially hard, so they do not wear out the cutting edge of the tool unduly. That points to one thing that will increase machinability — inclusions that will cause brittle chips and yet not be too abrasive on tools.

However, the very thing that makes high sulphur steels useful for fast machining makes it unsatisfactory for many mechanical applications. The high sulphur causes brittleness in the transverse direction; consequently, for such a thing as a heavily loaded spline shaft which needs high circumferential strength we would go a long way to avoid high sulphur material. (Another thing I might mention is that high sulphur and high phosphorus are unsatisfactory for welding and should be avoided.)

Lead has also been successfully added to steel to facilitate the cutting action. It apparently acts in essentially the same manner as sulphur, by producing discontinuities in the chip transversely, so it breaks without wearing the tools unduly.

Coming to the annealed steels, S.A.E. 3140 has a machinability rating of 45% (still on the basis of 100 for cold-drawn 1112). This means that in a given time and for a given over-all tool life, you can remove about 45% as much annealed 3140 steel as cold-drawn 1112 — or, if you remove metal at the same rate, the tool life will be somewhere around 45% as long. Notice again that the various *(Continued on p. 378)*



Hardness Increases in Affected Zones Alongside Welds in Various Plain Carbon Steels, Low Alloy Steels, and Engineering Alloy Steels (Theisinger and Warner)

Yoloy: Mn 0.30 to 0.90%; Cu 0.85 to 1.10%; Ni 1.50 to 2.00%
RDS: Mn 0.50 to 1.00%; Cu 0.50 to 1.50%; Ni 0.50 to 1.00%; Mo >0.10%
Cromansil: Mn 1.05 to 1.40%; Si 0.60 to 0.90%; Cr 0.80 to 1.10%; V >0.15%
4130: C 0.33%; Cr 0.50 to 0.80%; Mo 0.15 to 0.25%
4150: C 0.52%; Cr 0.80 to 1.10%; Mo 0.15 to 0.25%

An up-to-the-minute picture of the situation of all the metals was recently presented to officials of American engineering societies, with the hope that each would take necessary steps to inform the membership of the critical situations which exist, and to urge them to face the necessity of many substitutions

Conservation and Substitution Required by Metal Shortages

A FUNDAMENTAL CHANGE has occurred in the outlook of those governmental officials charged with the job of providing a flow of metals. Eight months ago one sensed a feeling of complacency; with the exception of two or three metals there was no acute shortage in view, even for civilian consumption. We were going to have our defense effort *and* business as usual, even more so. There was a list of seven "strategic" metals studied by the Ordnance Department (those for which strict rationing would be necessary in the unwelcome contingency of war) and three of the less worrisome "critical" metals. There was much comfortable conversation about "stock piles".

Today official Washington seems to be genuinely alarmed. Shortages abound. Transoceanic shipping is scarcer and scarcer. Stockpiles have become an illusion because industry absorbs the materials faster than the Government can buy and deliver them. At a meeting of representatives of American engineering societies, called Aug. 18 by ROBERT E. MCCONNELL, head of the conservation section of the Office of Production Management, the current situation for the important metals was outlined by the appropriate consultants. Satisfactory supplies existed for only four metals and the shortages included metals that were not even on the "critical" list eight months ago! Over and over it was emphasized that defense and lend-lease demands are constantly enlarging so that we are "reaching the bottom of the barrel".

Engineers throughout the country should therefore realize that conservation, substitution and even elimination are the order of the day, and take whatever steps are possible to meet the inevitable — to perform the necessary operations with the least damage and pain to the patient. To this end a series of conferences is being organized for the forthcoming National Metal Congress at the ASM Convention in Philadelphia, Oct. 20 to 24, and will occupy all afternoon and evening programs.

Since several articles have appeared in METAL PROGRESS beginning in February on the anticipated supplies and consumption of metals, this matter may properly be brought up to date at the same time we outline what can be done about it. The previous articles prove to have been correct statements of conditions at the time; changes have in nearly all cases come about by a large upward revision in anticipated demand. Now as to specific metals:

Aluminum was listed as a critical metal eight months ago. (A "critical" metal is "one which, while essential to national defense and secured in considerable portion from foreign sources, will be available locally in more adequate quantity.") As of Jan. 1, 1941, we were producing virgin ingot at the rate of 500 million lb. per year and had pro-

By Ernest E. Thum
Editor, Metal Progress

vided for a rate of 700 million a year later, an amount supposed to be sufficient for defense and also "to maintain civilian uses at the 1940 level". In the light of the recent scrap collection this sounds ridiculous. Requirements for aircraft have risen much more quickly than anticipated, and other requirements were underestimated, so the program now calls for ingot output at the rate of 1400 million lb. per year at the earliest possible time — probably achieved by Jan. 1, 1943, and an expenditure of half a billion dollars. Fabrication facilities must accordingly be doubled, power supplies searched out and allocated (power shortages are in prospect in a good many regions next winter). High grade bauxite ore from Dutch Guiana must now be supplemented by low grade Arkansas ore formerly classified as uncommercial.

Strict priorities on virgin aluminum caused a profound dislocation in the secondary metal trade. Foundries serving civilian uses (household utensils, engine parts, miscellaneous die castings) diverted the flow of scrap from the secondary smelters so that the latters' operations all but stopped. Another priority was then placed on scrap aluminum, which has brought production of secondary ingot back to around 75%, yet the balance being bootlegged is still sizable. Recent collections of household scrap, announced as netting roughly 10 million lb. of ingot, have been sold to secondary smelters, and this is about 12% of their expected 1941 make. It has not had the customary amount of cleaning and sorting in scrap yards, so it will melt into a high-iron mixture useful for killing steel.

(Footnote on veracity: One wonders how enthusiastically housewives would have donated aluminum to the Boy Scouts if they had been told what its real end would be. Instead, everyone read such statements as the following from F. H. LaGuardia, director of civilian defense, in his Aug. 27 summary of the campaign: "2800 fighting planes could be manufactured from 10,500,000 lb. of aluminum.")

Antimony, "a strategic metal, since over a period of years less than 10% of American requirements have come from mines in the United States" (Metal Progress, Feb. 1941, p. 176). The conclusion eight months ago, that stocks plus expected supplies from south of the Rio Grande would be sufficient for our needs, still holds good — so long as everybody does not try to make die castings out of lead-antimony alloy.

Chromium, also a strategic metal, was expected to be tight, but it was also expected that we could make shift until domestic sources became productive. That complaisance is gone. There is approximately one year's supply in this country at our present rate of consumption (750,000 tons of chromite). Metallurgical ore is mostly imported; two thirds from East African ports, one third from the Philippines and New Caledonia. Former sources of ore are now denied us (Turkey, Yugoslavia and Greece), the ore above ground in the other countries has been cleaned up, and ships are scarce. We are digging into our own inventories, and accepting lower grades of ores for smelting, so every effort must be made to utilize our scattered domestic deposits. (Next year these sources will yield only 75,000 tons.) The high grade deposit at Seldovia, Alaska, still lacks development, transportation and mild weather.

Obviously the metal must be used stingily. Stainless steel for novelties, decorative trim and household equipment is out. Use clad plate rather than solid stainless for heavy equipment. Downgrade the chromium content of the alloy steels to the lowest amount for the required duty.

Copper is not listed as a strategic or a critical metal, but is now spoken of in OPM offices as a precious metal! In round numbers the situation for the next 12 months is this:

Producing capacity in U.S.A.	1,000,000 tons
Expected imports	600,000
Available supply of new copper	1,600,000 tons
(which is a record by far)	
Defense (direct and indirect)	1,250,000
Balance for civilians	350,000 tons

which is about as much as Americans bought at the depth of the 1933 depression. So we're on poverty row even as to copper! Of course, these estimates can be knocked silly by a change in that item "needs for defense". Intensity of fire power per man is said to be 2½ times that of the 1914-18 war, and this locks up a very large amount of brass in small arms ammunition and field artillery cartridge cases until battlefield scrap starts to return. England is now using copper at about 1,000,000 tons a year, three times her previous maximum. The same ratio applied to our "normal" consumption of 800,000 tons of copper would put our requirements at the impossible figure of 2,500,000, impossible to achieve even if the expected maximum of 500,000 tons of secondary metal be added to the above figures for new copper.

The present 12¢ price is thought to cover nearly all the possible production; there is no more than 100,000 tons of marginal copper available to us, even at a higher price. Bonus payments for such metal are under consideration.

Conservation and substitution will obviously be necessary.

Two thirds of the non-military uses are for power, transportation and communications (verging on essential activities), and can only partially be replaced by high conductivity aluminum which itself is scarce. That means that one third of the copper and brass products, which are the foundation of whole industries making clocks, flatware, locks, plumbing goods and small hardware, are

going to be badly pinched. Galvanized pipe, flashing and guttering can take care of the building trades but the shop practices and traditional customs of the other fabricators will be ruthlessly violated by metallurgical substitutions.

Lead — almost a drug on the market in pre-defense days — caused no worry in the first half of 1941, but it now feels the impact of substitutions. For instance, it takes four times the weight of lead to make foil for cigarette packages, formerly of aluminum. The current demand for lead is simply enormous, and its commercial condition is worse than tin's. Can it be protective buying (euphemism for hoarding)?

Magnesium on Jan. 1, 1941 seemed to be ample for aircraft castings. The then capacity of 12,000,000 lb. from salt brines was to be increased to 20,000,000 by July by a sea-water plant on the Gulf Coast, and to 34 million during 1942. New needs for incendiary bombs and flares have multiplied the latter figure 12-fold! If this 400,000,000 lb. were all to be made by electrolysis it would take one quarter of the entire (undeveloped) power from the Grand Coulee dam. So it is a sizable undertaking. It has also brought forth a rash of proposals to utilize magnesite as raw material in untried smelting methods.

Manganese has long been known as the most necessary and strategic metal but, despite many appeals by technical men, nothing effective and non-political was done about accumulating a governmental stock pile. At the beginning of this year it was computed that ore on hand plus receipts from abroad could eke out 2½ years of capacity steel production. Even today, with Russian ore unavailable, there is enough manganese ore being mined in India, South Africa, Philippines, Cuba and Brazil, but the shipping shortage is such that we are barely holding our own. Demands are increasing, also, because steel production is increasing, and — what with priorities on nickel, chromium and vanadium — more and more manganese alloy steel is being made. As for American ore, the Butte mines are already producing 80,000 tons a year in the operation briefly described in "Critical Points" for August; next year this and other sources will make 200,000 tons of metallurgical ore; in 1943 perhaps 400,000 — but even that would be only one quarter of our annual demand. New processes for utilizing our vast tonnage of manganiferous iron ores and nodular material are as yet only in the "pilot mill" stage (if that) and are not being prosecuted with anywhere near the necessary vigor.

No substitute for manganese in steel making is known.

Mercury is very easy. We have so many low grade deposits in the Pacific mountains that production parallels the price upward. Likewise we have agreed to take the 2000 flasks that Mexico was formerly shipping to Japan every month. So our expected requirements of 45,000 flasks for 1942 are in sight. Likewise there are some known and usable substitutes for fulminate in primers and ammunition detonaters.

Molybdenum supply has been discussed pessimistically elsewhere in this issue (page 304), and notes on our principal sources presented in "Critical Points" for July and August. Official opinion is decidedly more optimistic, relying on the present visible stocks of 22 million lb. of metal, present production at the rate of 42 million annually (expansible to 50 million by increasing the mill at Climax to the capacity of the mine haulage tunnel), and a "normal" American consumption of about 7 million.

Nickel on January first was a little scarce, but nobody seemed to be worried much. By February the principal producer was carefully allocating shipments, and by March tight priorities were clamped down. The present situation regarding imports and consumption is not materially different from that analyzed in METAL PROGRESS in the March issue (page 301). We are importing 15 million lb. a month and there is an apparent demand (defense, auxiliary and civilian) for about 20 million. Inventory and stock in process is only two weeks' supply. It is authoritatively stated that the imports are considerably more than the unmistakable requirements of the defense effort, but obviously these are so great that currently less than 1,000,000 lb. per month is left over for civilian uses. What can be done in the way of substituting for nickel steel (and this amounts to half of the demand) is discussed on page 300 of this issue.

Platinum is available in such large quantities as a by-product of the Canadian nickel refineries that large stocks of refined and crude are held on both sides of the border. The only metal of the platinum group that is giving worry is iridium, used for hardening platinum for contact points and spark plugs. British requirements have absorbed the available supplies from Alaska and South Africa. (Russia cannot ship.) Another dredge in the placer field in Alaska will probably meet our minimum requirements. Meanwhile the jewelry trade has been urged to use ruthenium (which is cheaper and readily available) for a platinum hardener.

Steel. Space forbids a recital of the long controversy over the adequacy of our steel plants. Men in the steel industry have contended stoutly that they can easily produce all that can be fabricated into Marine, Army, Navy and Aircraft requirements. A considerable body of opinion in the governmental bureaus holds, however, that civilians must not be denied, and that capacity should be largely expanded for business as usual.

GANO DUNN, a well-known and respected engi-

From Such Mountains, Far Above Timber Line, Comes Bolivian Tin. Portal of main tunnel is in walled cut in left foreground. OEM Defense photo of Patino mines at Catavi.

neer acting as consultant to OPM, made an elaborate report to the President on Feb. 22 about the adequacy of the steel industry for national defense. He computed the maximum reliable steel producing capacity of the industry as of Jan. 1, 1941 at 87,576,099 tons per year. Expansion then under way or shortly thereafter indicated 91,338,669 tons by Jan. 1, 1942. Full operation would involve comparatively small deficits in coke ovens, Great Lakes transportation and blast furnace capacity. Direct Army and Navy requirements (exclusive of barracks, roads or expanded plant facilities) were estimated as 4,100,000 tons for the fiscal year ending June 30, 1942, and 350,000 tons more for the 78 ships to be built by the Maritime Commission. British needs (munitions, ships, commercial steel) and other exports were estimated at 13,440,000 tons in 1941. Defense, as visualized then, obviously would not strain our capacity to produce steel.

Three months later the shortages anticipated in auxiliary operations had been arranged for, but the requirements had changed, largely from stepped-up estimates by Army, Navy and Air Forces, and passage of the Lend-Lease Act. Added to this, bureaucratic estimates for civilian "requirements" grew even more rapidly. In Mr. DUNN's second report to the President on May 22 he indicated that to satisfy the latter the steel capacity for 1942 would have to be upped 30 million tons to 120 million, which amount could not be produced and fabricated with the available labor. Even to increase capacity 10 million tons would take two years' work of half a million men, and withdraw 4,160,000 tons of steel from the current supply when we need it most. He said, "There is no question of lack of steel for national defense. The grand total of all the Army, Navy, Maritime and other military requirements, plus all-out aid of every kind for Britain, is less than 25% of the industry's capacity."

Mr. DUNN's picture of an orderly but moderate increase in steel making capacity was apparently not acceptable to the high command, for early in June an announcement was made by OPM that steel capacity must be increased several million tons, starting as soon as financial arrangements could be made. Some plans toward that end have already been announced by the three largest steel corporations. Meanwhile official opinion seems to be rather easy — that the immediate situation can be handled by "directing" steel into proper channels, *i.e.* by priorities, which were instituted recently. It is not necessary here to give instances of how this works.

Probably the urge to build new openhearth departments has been dampened by difficulties in getting enough pig iron and scrap to feed the ones we now have. Mr. DUNN's tabulation for requirements as of Jan. 1, 1942 (basis 91,338,669 tons of steel) follows:

Pig iron	51,607,718 tons
Home scrap	27,401,601
Purchased scrap	21,463,217
Total metallic charge	100,472,536 tons

In addition to this, 1 million tons of scrap was estimated for export to England, and 10 million tons for American foundries.

This estimate is too modest; 31 million tons of scrap have been used in the first seven months of 1941, and it has recently failed to appear at this enlarged rate. To forestall a permanent shortage, present emphasis is to increase blast furnace capacity (with accompanying lake transport and coke ovens) by some 6½ million tons beyond the 2 million-ton building program already under way. No iron from these paper furnaces can be expected short of 15 months.

The solution now obviously is to offer what it costs to collect the out-of-the-way scrap that undoubtedly exists in sufficient quantity, and pay

its freight into the steel-making centers. Such a plan was proposed by consultants to OPM more than two months ago, but instead Mr. HENDERSON's (now defunct) OPACS issued a complicated "ceiling" of prices that could not be enforced or policed, so it never took effect. There is at least 7 million tons of scrap in auto graveyards, and an even larger though undetermined amount on the farms. A campaign to induce the farmer to bring it in to the nearest scrap yard is under discussion; in any program of this sort it is to be hoped that the mistakes and double-talk of the aluminum campaign will not be repeated.

Tin was the first metal to be given anxious attention a year ago when the emergency suddenly arose. To supplement privately held supplies, the Metals Reserve Co. contracted for a 75,000-ton stock pile, and later doubled this amount. However, this pile grows but slowly. Current imports are somewhat more than consumption, and since Jan. 1 the visible stocks have increased one quarter and now total about 15 months' consumption. Our new (and only) tin smelter in Texas City will start operations about Feb. 1, 1942 and will produce 19,000 tons of tin per year from the Bolivian and Dutch East Indian ores that can be bought. Present American consumption is up to 105,000 tons of new tin yearly (as against 75,000 tons for a "prosperous" year).

Conservation to the extent of 10,000 tons a year will come largely through a reduction of the coating on tinplate; the 1.5-lb. per box tinplate has been changed to 1.35 lb. Terne plate or lacquered black plate is also being used for such substances as can safely be packaged. About 1500 tons of tin will be saved by using a lead-tin alloy for collapsible tubes for shaving creams.

Tungsten supply has been discussed at length in METAL PROGRESS for February and April (page 461). The conclusion that we would have enough for 1941, if it is husbanded, checks with present official opinion. Husbanding has been necessary, as proven by the requirement that the tungsten-molybdenum high speed steels be used on non-defense operations. Estimates for 1941 and 1942 are as follows:

	1941	1942
Requirements	*15,000,000 lb.*	*20,000,000 lb.*
U.S.A. production	6,200,000	8,000,000
Southern countries	3,500,000	6,000,000
Portugal	1,000,000	1,000,000
China	more than 6,000,000	?

Then, as now, the nub of the problem consists of ships from the Far East. Likewise, an unlooked-for demand for a tungsten alloy for defense would upset all the figures.

Vanadium. The "normal" consumption of 1,400,000 lb. vanadium per year (all procurable from within the States) is now up to 3,400,000 lb. with a further increase demanded in 1942. All that can be had here and from Peru and from the rest of the world comes to only 4,500,000 lb. Conservation is necessary — for here is where substitution gets you: When no nickel carburizing steels are available metallurgists turn *en masse* to the chromium-vanadium steels, and soon there is no vanadium. (More remarks on substitutes for the substitute are on page 303.)

Zinc was studied at length in METAL PROGRESS for May. The figures given there have not been substantially changed. There is a present shortage as measured by demand, but no actual shortage for defense and the basic civilian economy. As to the future, anticipations are not so hopeful, for there seems no way to increase the supply. Requirements for ammunition are bound to go up, so conservation is essential. Notable results have already been achieved (but to the discomfiture of the die casting industry) by cutting the amount on automobiles from 50 lb. per car to 16 lb. — 100,000 tons saved here. Another move that has resulted in less dislocation of labor is to deny zinc for galvanizing to the large steel mills and reserve it for the small custom plants which do nothing else.

Simplification and Standardization

Since so much has been said about the needs of substitution for civilians, it is fair to ask whether the armed services are aware that this need may eventually reach them. The answer is that but little attention has as yet been given to this. To be approved, any change must satisfy the following requirements: *(a)* it must be into material for which there is undoubtedly a larger available supply; *(b)* the substitution or simplification must result in no impairment of military function; *(c)* there must be no delay in delivery.

The Federal Specifications Committee is now preparing "emergency alternate specifications" for use when specific raw materials become really scarce. However, considerable store is set on the effort to simplify the present specifications used by industry. This is undoubtedly important, and will result in a comparatively modest increase in the material made available to industry from a given tonnage of ingot.

Another change that will mean far more in actual supply is hardly under way. It is a fundamental change in the philosophy of specifications, toward the Continental model. *We* specify by composition, and therefore multiply varieties through worry about minor "impurities" of unknown and often negligible importance; *they* specify by properties desired, and let the metallurgist produce what he will to meet those requirements. About all we have done in this respect is to remove the word "virgin" from many specifications, thus admitting secondary metal of proper analysis.

The Editor has observed various equipments for electrolytic polishing, ranging from a beaker with metal clothes pins, through glass battery boxes under hoods, to elegant self-contained equipment in mahogany cabinets, but this is the first article about them he could get written

An Improved Cell for Electrolytic Polishing

By Orlo E. Brown
In Charge of Metallurgy
and C. N. Jimison
Graduate Student
West Virginia University
Morgantown, W. Va.

WITHIN THE LAST FEW YEARS there has been a great deal of attention focused on the electrolytic polishing and etching of metallurgical specimens. The possibility of replacing the tedious procedure on polishing wheels with a simple electrolytic method has had universal appeal. As a result there has been a great deal of research to determine the factors involved in controlled electrolysis.

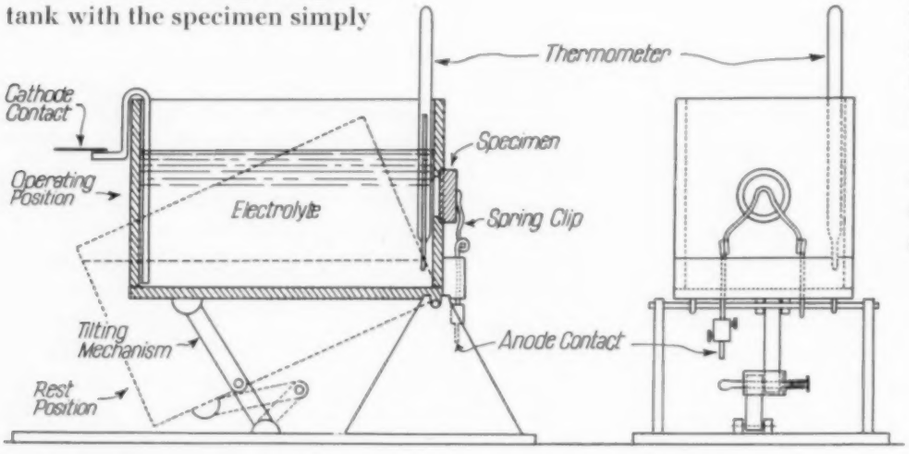
Judging from the literature, there has been, however, relatively little work done on developing a really simple yet suitable apparatus for this improved operation. Most investigators seem to have used either a beaker or a rectangular glass tank with the specimen simply hung in the electrolyte, electrical contact being made through the wire or clip which suspended the specimen. Such a method of handling ignores certain basic requirements of electrolytic polishing, the most important of which are as follows:

1. The current density on the specimen should be accurately controlled, since the satisfactory range for most metals is narrow.

2. The specimen must not be in contact with the electrolyte except when the current is flowing.

3. The specimen should be washed and dried immediately following treatment; this requires that the specimen be easily and quickly removed from the apparatus.

4. The position of the specimen during polishing or etching should be fixed so that no unnecessary

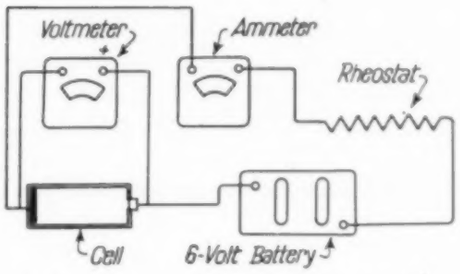


Scale Drawing of Electrolytic Polishing Unit, Indicating Its Position When Not in Use. A U-tube for circulating cold water can be used to keep the electrolyte down to safe temperature when tank is in constant use

variable (of internal resistance) will be introduced.

The temperature of electrolyte should be easily controlled.

The accompanying illustrations show a cell which satisfies all of these requirements. In addition it is of simple construction. It will be noted that the round specimen or its mount forms the closure for the opening in the end of the tank and is held tightly in place by a spring clip which also makes the electrical contact. This means of holding the specimen has the double advantage of speed (the sample can be very rapidly inserted or removed) and of limiting the attacked area to that of the opening. Current density can therefore be accurately controlled.



Wiring Diagram of Experimental Set-Up. After proper conditions are discovered, repetitive work can be done merely by setting rheostat for correct resistance

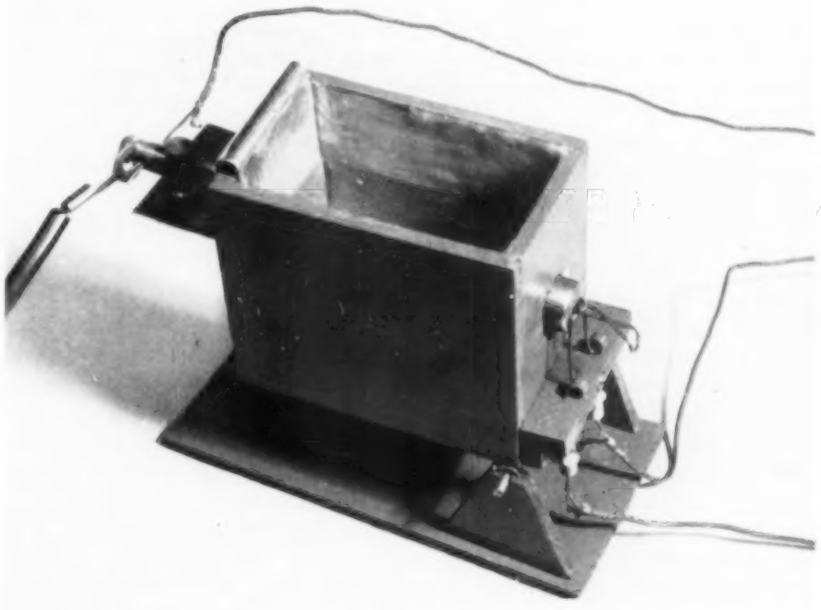
The cell has a rectangular shape and, for microscopic specimens, can be rather small. Satisfactory results have been obtained by the authors with a wooden box whose inside dimensions are 2 in. wide, 3 in. deep and 3½ in. long. The hole which the specimen covers is made ½ in. in diameter, although this can be made any size which the operator may prefer. Wood is used for the construction, the inside of the container being coated with paraffin. It should be mentioned that bakelite is not to be used where it will come in contact with the electrolyte, for at least one of the electrolytes commonly employed for electrolytic polishing attacks bakelite and will be rendered unusable by a bakelite container or mount for the metallic specimen.

The cell as shown does not have any provision for regulating the temperature. In most instances the temperature of the electrolyte does not vary sufficiently during the preparation of a specimen to warrant any special control. However, when several specimens are to be prepared in rapid succession it is recommended that a U-tube containing circulating cold water be inserted in the cell to prevent temperature rise. It has been found that a mechanical stirrer is not satisfactory, for any forced motion of the electrolyte will cause an uneven attack on the metal surface and give a rippled effect.

There is no contact between electrolyte and specimen when the tank is in the tilted position. The operator is free to insert the specimen in place and see that it is firmly seated without any contact with the electrolyte whatsoever. When the tank is raised to the operating position, the electrolyte covers the metal, thus closing the electrical circuit. This fully satisfies the second requirement.

Removal of the specimen is quickly accomplished by touching the toggle joint and, as the tank lowers, the specimen is taken from beneath the clamp. It is advisable to have running water at hand so that a thorough washing of the polished metal surface may be accomplished immediately.

If the above procedure is followed, the mechanical difficulties usually encountered in electrolytic preparation of specimens will be eliminated.



Wooden Box, Paraffin Lined, Tilting on One Edge, Forms Satisfactory Cell

A special committee was appointed by the American Iron & Steel Institute to consider what could be done about the shortage — almost embargo — on nickel steels of low and medium alloy content. It prepared an 80-page pamphlet of the title below, from which the following text is extracted

Possible Substitutes for Nickel Constructional Steels

BEFORE CITING specific cases in which the nickel content of steels compounded to perform specific duties may be reduced, or even eliminated, certain limitations must be accepted and certain assumptions made:

(1) It must be clearly understood that substitution frequently involves sacrifice. Steels having identical tensile properties may exhibit widely varying impact and distortion characteristics; others having almost identical hardenability characteristics exhibit widely varying other physical properties. In some cases a compromise with the optimum is all that is possible; in other cases the substitute steel will be found to be as satisfactory in every respect as the steel which has been replaced. . . . .

(3) For certain uses nickel steels are indispensable although for other uses the quantity of nickel now being used may be reduced or replaced by some other element or elements. . . . .

(4) In order successfully to substitute for a given grade of nickel steel, careful study must be given to published data on physical properties and heat treatment characteristics. . . . . The selection and application of constructional alloy steels is seldom dependent upon tensile properties alone; it is usually a compromise involving many factors. Size of section is of prime importance and in some cases the effect of nickel in large sections may be difficult to duplicate; in that event users of such steels, in order to use substitutes, will have to consider redesigning the object under consideration. In this connection the wide experience of steel manufacturers should be drawn upon freely.

(5) Substitution may involve changes in fabricating methods, heat treatment procedures and facilities for its control. Some grades of steel are fabricated by torch-cutting, bending, forming, dishing, drawing and other such methods, all of which make substitutions quite difficult without the stipulation of heat treatment of some sort.

(6) Steel consumers should check carefully their facilities for heat treatment, metallurgical control, and all phases of manufacture such as forging and machining techniques. Characteristics of finished parts should be analyzed carefully for such factors as decarburization, distortion, fatigue properties, impact requirements involving temperature gradients, and high or low temperature service.

Substitutes for Carburizing Types

The carburizing steels most commonly used may be divided into four distinct classes:

(1) Those which are quenched directly from the carburizing temperature.

(2) Those which are pot-cooled from the carburizing temperature. reheated and quenched in oil.

(3) Those which are quenched directly from the pot, followed by tempering.

Extracts from a report issued by
American Iron & Steel Institute
(with a footnote by The Editor)

Table I — **Carburizing Grades; Direct Quenched**

Steel	Tensile Strength	Yield Point	Izod Impact
Nickel steel 2320	150,000	122,000	45
Substitutes: 4620	130,000	100,000	45
3120	135,000	105,000	32
4120*	137,000	105,000	35
6120*	130,000	110,000	55
4022*	130,000	95,000	45
Nickel steel 2512	175,000	148,000	45
Substitutes: 3315	208,000	165,000	45
4820	182,000	150,000	42
4320	180,000	160,000	40
Nickel steel 3120	135,000	105,000	32
Substitutes: 4120*	137,000	105,000	35
6120*	130,000	110,000	55
4022*	130,000	95,000	45
5120*	128,000	104,000	33
Nickel steel 3315	208,000	165,000	45
Substitute: 4320	180,000	160,000	40
Nickel steel 4620	130,000	100,000	45
Substitutes: 3120	135,000	105,000	32
4120*	137,000	105,000	35
6120*	130,000	110,000	55
4022*	130,000	95,000	45
Nickel steel 4820	182,000	150,000	42
Substitute: 4320	180,000	160,000	40

*These steels contain no nickel.

(4) Those which are pot-cooled followed by two reheating and quenching operations.

The quantity of steels treated by the method set forth in paragraph (4) represents small tonnage.

The most commonly used nickel-containing carburizing steels and possible substitutes therefor are shown in the following tabulations, which also contain the important physical properties as determined on standard test pieces cut from the axis of 1-in. bars, pseudo-carburized 8 hr. at 1680° F., oil quenched and drawn 1 hr. at 400° F.

Many grades within the suggested classes have been developed for specific uses over a long period of time. Since the original development of these steels, improvements in engineering design have been made which will, in some cases, permit the use of steels with lower ductility. Careful consideration should be given to that fact when considering substitutes.

Steels containing a higher molybdenum content than the regular 4100 and 4300 series are in the development stage. The aim is to increase the strengths without materially affecting the ductility.

Substitutes for Deep Hardening Types

The deep hardening alloy steels most commonly used may be divided into three distinct classes.

(1) The 0.25 to 0.35% carbon class, used in the oil or water hardened state within a tensile strength range of 100,000 to 150,000 psi. and a Brinell hardness number range of 200 to 300. The nickel steels of this group which are most commonly used are 2330, 3130 and 3135.

(2) The oil hardened 0.40 to 0.50% carbon class, divided as follows:

(a) Those used in the full hardened state, tempered to about 400° F. with resultant Brinell hardness of 550 to 600, within a tensile strength range 275,000 to 300,000 psi.

(b) Those treated to Brinell hardness of 350 to 450 within a tensile strength range of 175,000 to 225,000 psi.

(c) Those treated to Brinell hardness of 275 to 325 within a tensile strength range of 140,000 to 170,000 psi.

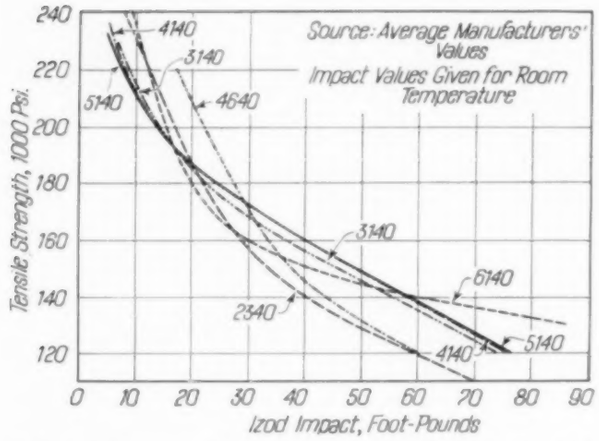
The nickel steels of this group which are most commonly used are: 2340, 3140, 3145, 3150, 4340, modified 4345, 4640 and 4650.

(3) A specialty class of alloy steels containing approximately 0.60% carbon, used for

Table II — **Carburizing Grades, Double Quenched for Maximum Izod Values**

Steel	Reheat	Tensile Strength	Yield Point	Izod Impact
Nickel steel 2320	1475	135,000	110,000	45
Substitutes: 4620	1500	120,000	95,000	48
3120	1500	130,000	98,000	40
4120*	1575	120,000	102,000	40
6120*	1500	120,000	87,000	23
4022*	1525	115,000	90,000	45
Nickel steel 2512	1475	173,000	140,000	53
Substitutes: 3315	1475	210,000	170,000	43
4820	1450	167,000	137,000	57
4320	1500	185,000	160,000	55
Nickel steel 3120	1500	130,000	97,000	40
Substitutes: 4120*	1575	120,000	102,000	40
6120*	1500	120,000	86,000	23
4022*	1525	115,000	90,000	45
5120*	1525	119,000	97,000	39
Nickel steel 3315	1475	210,000	170,000	42
Substitute: 4320	1500	185,000	160,000	55
Nickel steel 4620	1500	120,000	95,000	48
Substitutes: 3120	1500	130,000	97,000	40
4120*	1575	120,000	102,000	40
6120*	1500	120,000	87,000	23
4022*	1525	115,000	90,000	45
Nickel steel 4820	1450	167,000	137,000	57
Substitute: 4320	1500	185,000	160,000	55

*These steels contain no nickel.



Relation Between Tensile Strength and Izod Notched Bar Values for 1-In. Rounds of 0.40% Carbon Alloy Steels. Heat Treated to Various Strengths. Tests made at room temperature. (Average manufacturers' values)

a variety of purposes such as piston rods, rams, sow blocks, trimmer dies, shear blades, and hot-work dies. The nickel steels of this group which are most commonly used are chromium-nickel steels, chromium-nickel-molybdenum-copper steels and chromium-nickel-molybdenum-vanadium steels. It will be most difficult to duplicate the properties of such steels with other chemistry combinations without considerable experimental work.

In addition to the substitutions suggested in Tables I and II, these may be considered:

Nickel Steels	Possible Substitutes
3000	4000, 4100, 5100, 6100
3200	3100, 4000, 4100, modified 4100, 6100
3400	Modified 4300
4300	No substitute suggested

Numerous charts are given in the pamphlet [and are available in other publications] representative of typical physical properties obtained after quenching one-inch round samples of the various types of steel listed and drawing at various temperatures. Such values should not, however, be used to set specification limits. Data are constantly being assembled by steel manufacturers and as new experience is gained published data may have to be modified. Then, too, minor changes in chemistry combinations and manufacturing techniques may cause major changes in one or more physical properties.

In order to exhibit the differences in ductility which might exist between various types of quenched and tempered steel at the same tensile strength, graphs have been drawn in which hardness, yield point, elongation and reduction of area are plotted against tensile strength values. From these it is clear that little difference exists when the several steels are properly compared.

Impact values of the several steels referred to above were compared with their respective tensile strengths, and plotted in the first graph. The nickel steels exhibit superior properties at high strengths, an advantage which does not exist in like degree at lower strengths.

The relationship between hardness and Charpy notched bar value was studied and the results given in the second engraving are reasonable expectances in a temperature range of —50° F. to room temperature.

Because a comparison of the properties of small sections is not adequate to describe fully the differences which exist among the several steels, hardenability charts are given of 1-in., 2-in. and 3-in. rounds quenched in oil, and 2-in., 3-in. and 5-in. rounds quenched in water. [These are reproduced in the Data Sheet, page 305.]

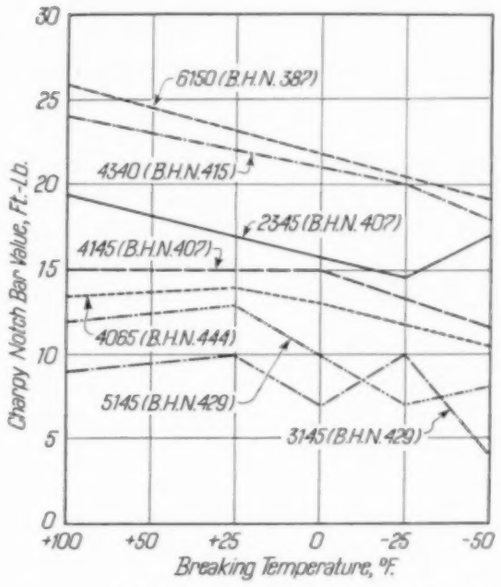
Comments by The Editor

Since supplies of nickel have been "tight" since the first of the year, and the metal is one of the first to be reserved for ordnance purposes, manufacturers of consumption goods for civilians have been forced into substitutions as their stocks became exhausted. Substitutions in the carburizing grades have gone particularly toward the 6100 series (chromium-vanadium) with the inevitable result of depleting the supply of these two imported elements — especially vanadium — consequently there is a good prospect that even this haven of refuge will be denied the manufacturer of gears, shafts, mechanical bearings, pins and collars.

In view of this situation, foreseen many months ago, the series of articles by Gordon T. Williams on "The Proper Selection of Steels" has been particularly timely. He emphasizes over and over again that, although alloy steels may appear to be interchangeable on the basis of tensile properties and hardness, the economic choice for a particular duty must inevitably

depend on the metallurgical characteristics (particularly hardenability and grain size), the existing heat treating equipment, the machinability and — of paramount importance today — its availability on the market. (These excellent articles, by the way, are being assembled in a book which will be ready early in October.)

Nickel steel has good reason for its widespread acceptance. It has been under continuous competition from steels made with other and cheaper alloys. Nevertheless, it has not only stood its ground, but by virtue of intelligent promotion by the chief producer, has expanded its utility in keeping with the larger consumption of alloy steels, year by year.



Charpy Notch Bar Values at Sub-Normal Temperatures for Specimens of Alloy Steels Heat Treated to Approximately 400 Brinell Hardness. Source: Manufacturers' values

It is doubtless very discouraging to find now that customers, gained and held with such efforts, are unable to be supplied with necessary metal. Robert C. Stanley, president of International Nickel Co., said in a recent letter to stockholders and consumers:

"In order to meet the greater demands of the Army, Navy and Air Services of Canada, Great Britain and the United States, substantially increased amounts of nickel have been made available. All production facilities of this company are operating at full capacity. In spite of this, hardship is being inflicted upon many consumers of our products who in the past have aided us in building a great business, and upon whom we must depend for our future success.

"Many of them have been compelled to attempt substantial alterations in their operations. We are offering them the full cooperation of our research and technical organizations in meeting this difficult situation and many of our activities formerly concerned with sales and services are focused on providing this help.

"Upon the conclusion of this devastating war the future success of your business and ours will depend in large measure upon the retention of the good will of our customers. Any effort we can make, not conflicting with our full support of the defense program, should be directed toward this vitally important objective."

Fortunately for the American metallurgical industry, a great deal of fundamental work has been done within the last decade on the exact function of the various alloying elements in steel. Edgar C. Bain's book on that subject is a masterly summary of the available information. Hence the information is now available for an intelligent attack on the problem. The steel manufacturers have also learned how to make fine-grained steel without depending entirely on the element vanadium; aluminum properly applied does the trick, and just emerging in practical use are some complex combinations of rarer elements that have remarkable influence on grain size and hardenability even when used in "traces".

It is now up to the steel consumer to absorb this available information and become accustomed to specifying steel by its *properties*, rather than its composition. What he usually requires is a steel of a certain strength (and this is roughly measured by its hardenability), toughness (by its grain size), and machinability (by its grain coarsening temperature), and he shouldn't care how the steel maker makes it, or what alloys he puts into it, or how much. Knowing what is required in steel for his machinery and then permitting the steel supplier to give him these properties in any available metal — *that* is intelligent substitution.

In fact, this practice appears to be inevitable, and for the following reasons: The common alloying elements for steel are very few. Everyone knows about nickel, chromium, vanadium, molybdenum; many appreciate that manganese and silicon are also useful; few are ready to accept phosphorus and copper. However, the supplies of nickel, chromium and vanadium, all being imported in major quantities, cannot be relied upon for civilian uses. That leaves molybdenum, manganese and silicon. Silicon — easily procurable — now enters

engineering steels only with sizable amounts of manganese, molybdenum or chromium. As for manganese, HARRY MCQUAID is fond of saying it is the only essential alloy, and for many years there has been an increasing trend toward higher manganese in many of our heat treatable steels, but it is so essential to counteract the inevitable sulphur and oxygen in all steel, even the commonest, that there may be little available for alloying additions, what with our meager supplies.

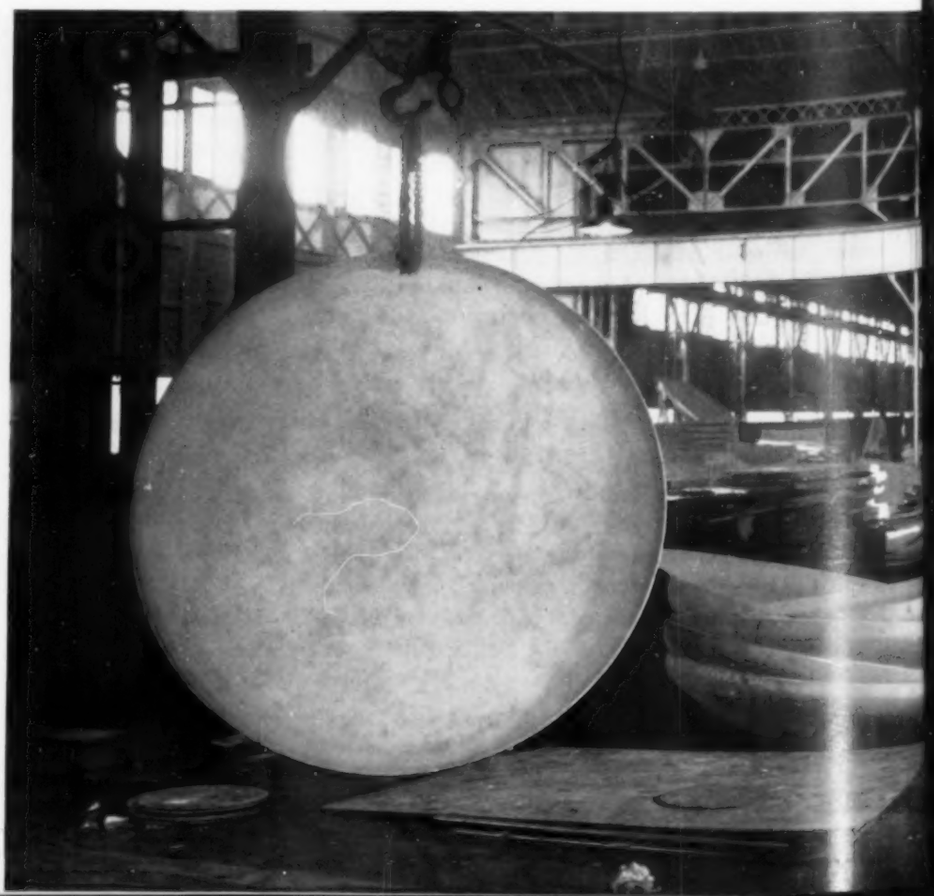
That throws us back on molybdenum and, thanks to 20 years of study by the steel industry, working with the automobile industry and the alloy producers, it appears to be able to step into the breach marvelously and, with a modicum of manganese, silicon, nickel or chromium, to produce steels of excellent hardenability, toughness, machinability, weldability and wear resistance. And most everyone seems to believe we will have ample molybdenum, since there is so much being produced within our own borders. But have we?

In "Critical Points" in the July and August issue will be found some facts about the principal producers. Climax Molybdenum Co., operating at the capacity of its mill, will produce 27,500,000 lb. of molybdenum metal. The porphyry copper mines associated with Utah Copper Co. will make 12,000,000 lb. more as a byproduct. Other American producers will make 1,500,000 lb., and probably another million or so will be got just over the line in Mexico. That makes a total of 42,000,000 lb. of molybdenum to play with.

Deduct right off the bat 15 million for special ordnance steels having nothing to do with machinery, another 10 million for export to Britain and Canada, 2 million for toolsteels, and we find that the remainder would make about 3,000,000 tons of conventional alloy steels containing 0.25% molybdenum, or only 1,500,000 tons of the higher molybdenum steels proposed as substitutes for the nickel steels (modified 4100 and 4300 series). Much of this will be absorbed by defense contracts, and whether there will be any left over for civilian consumption of such excellent steels as the "Amolas", the 1.30% Mn steel with 0.30% Mo, and the 1% Si steel with 0.50% Mo (all well tried and now in tonnage production), depends largely on whether the principal producer can increase its output largely and how fast. At any rate, there does not seem to be an unlimited amount, nor even any comfortable surplus of molybdenum in sight right now.

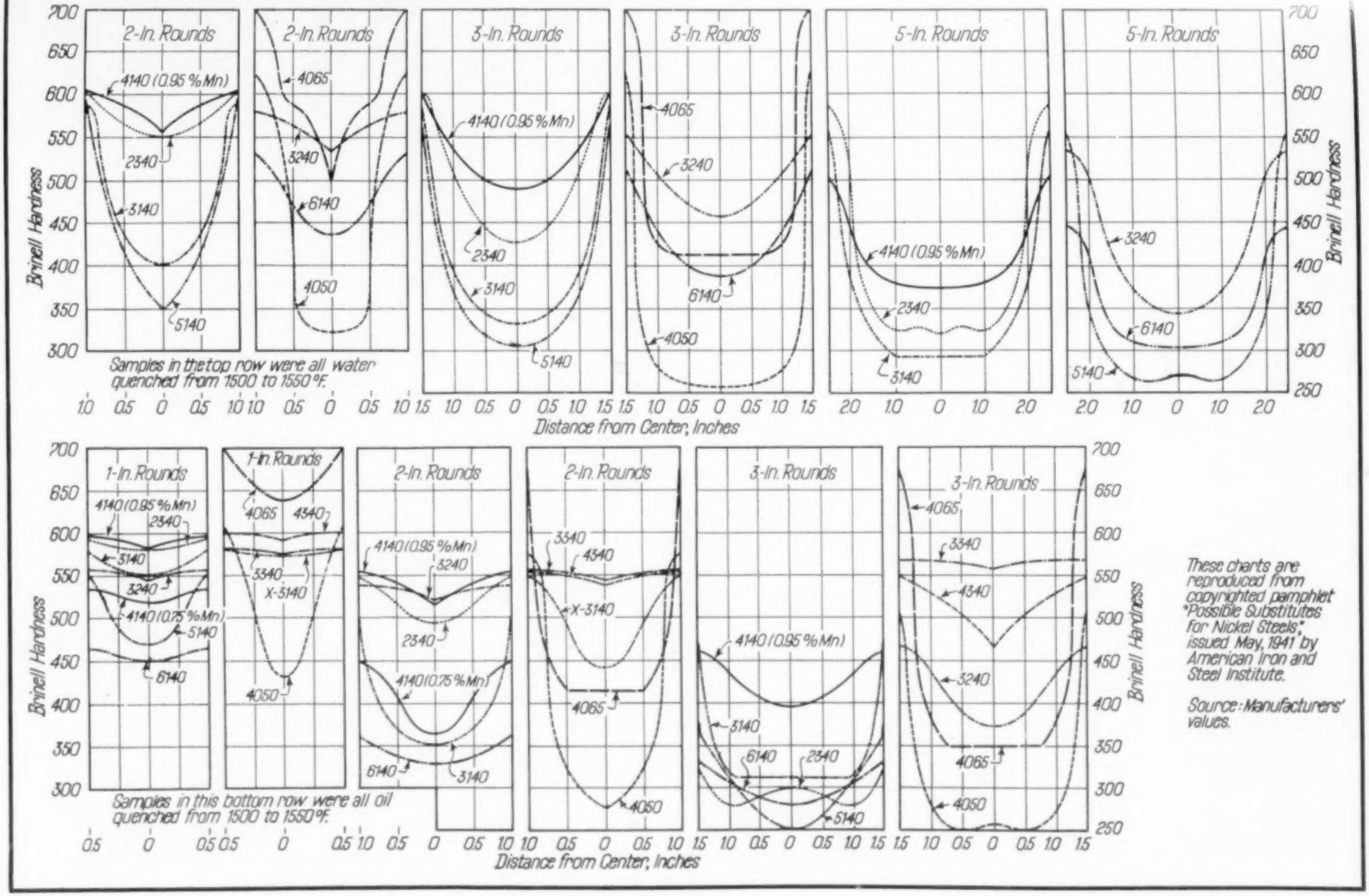
No matter where you turn, you seem to run into shortages. That really is to be expected. Shortages not only for civilian requirements but also for military. To stave off the latter it would be the part of wisdom, right now, to organize a group of the best metallurgists in the Army, the Navy, the Air Corps, the steel industry, and the automotive industry, to give their undivided time to the study of *requirements* of steels for defense equipment.

Delay may be disastrous, for time appears to be approaching that we can't give even the Army and Navy all the 5% nickel steel (say) they ask for. Is it too much to expect the defense industries to do what the civilian suppliers must perforce do? — specify steels not by composition, but by strength (hardenability), toughness (grain size) and machinability (grain coarsening temperature).



A Good Example of Conservation. These are flanged and dished heads, 108 in. dia., of stainless clad steel; plate made by Jessop Steel Co.; hot spinning done by Lukens Steel Co.

Hardening Characteristics of Common Alloy Steels Containing 0.40 to 0.65% Carbon



These charts are reproduced from copyrighted pamphlet "Possible Substitutes for Nickel Steels," issued May, 1941 by American Iron and Steel Institute.

Source: Manufacturers' values.

A TREASURE CHEST
of useful information...

From time to time over a period of years our technical staff has unearthed new facts concerning metals. This wealth of information has been accumulated out of wide experience in the solution of problems involving the use of Nickel and its alloys.

On the basis of this experience much helpful literature has been compiled. Dealing with the selection, fabrication and use of Nickel alloys it can be of great help to the metal working industries at a time like the present.

In addition to printed matter, we are glad to make available the assistance of our technical staff in solving problems arising from a temporary lack of Nickel. Your request for literature or personal consultation will receive our prompt attention.

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK, N. Y.

In view of a possible shortage in tungsten later in 1941 the Office of Production Management on June 11 issued an order requiring all users of high speed steel to accept at least half their current requirements in low tungsten, high molybdenum steel. Since many users are unfamiliar with its treatment, the following recommendations have been issued

Heat Treatment of Molybdenum High Speed Steels

IT SHOULD be borne in mind that where hardening equipment is available in which decarburization can be controlled, there is no particular problem involved in replacing the tungsten high speed steel with the proper molybdenum high speed steel. There are differences in hardening temperatures and timing cycles, but the broad general principles are similar.

Where proper equipment does not exist, the special precautions indicated below should be helpful.

High speed steel is defined by the Office of Production Management in General Preference Order M-14 as follows:

"The term 'high speed steel' as herein used is defined as including two classes of alloy steels:

"(i) 'Class A high speed steel' is hereby defined as either alloy steel containing not less than 0.60% carbon and containing more than 3.0% molybdenum; or alloy steel containing not less than 0.60% carbon, containing 7.0% or less tungsten, and containing more than 3.0% molybdenum.

"(ii) 'Class B high speed steel' is hereby defined as alloy steel containing not less than 0.55% carbon and containing more than 12.0% tungsten.

"*Note:* Other alloy materials may be present in the steels of either class, but steel not containing the substances named, in the amounts specified, shall not be considered high speed steel."

The compositions for molybdenum high speed steels as given in Table I include only those steels most widely used and established for general commercial tool applications. There are additional compositions which are used for special applications. Since they require special heat treatment to properly handle, their use is not discussed in this practice.

For those who are not skilled in handling molybdenum high speed steels and who do not have decarburization under good control, it is recommended that at present they adopt the following procedure:

1. Use the required substitution of molybdenum high speed steels, selecting the type that will produce the best results and give the least trouble in working. The smaller tools are heat treated by shorter cycles and thus the general hazards are less.

2. Proceed on the basis that steels of Type III decarburize less than steels of Type I or II. In most cases steels of Type III can be treated without surface protection in the same equipment used for tungsten high speed steels.

By a special committee of O.P.M.:
Norman I. Stolz, Chairman
J. H. McCadie
W. H. Wills
F. Lloyd Woodside
J. Edward Donnellan, Secretary

Table I—Compositions for Molybdenum High Speed Steels

Element	Type I, Molybdenum-Tungsten		Type II, Molybdenum-Vanadium	Type III, Tungsten-Molybdenum
	Type I*a*	Type I*b*		
C	0.70-0.85	0.76-0.82	0.70-0.90	0.75-0.90
W	1.25-2.00	1.60-2.30	.....	5.00-6.00
Cr	3.00-5.00	3.70-4.20	3.00-5.00	3.50-5.00
V	0.90-1.50	1.05-1.35	1.50-2.25	1.25-1.75
Mo	8.00-9.50	8.00-9.00	7.50-9.50	3.50-5.50
Co	See footnote	4.50-5.50	See footnote	See footnote

Note — Cobalt may be used in any of these steels in varying amounts up to 9.00% and the vanadium may be as high as 2.25%. When cobalt is used in Type III, this steel becomes susceptible to decarburization. As an illustration of the use of cobalt, Type I*b* is included. This is steel T-10 in the U.S. Navy Specification 46S37, dated November 1, 1939.

3. Consult with the firms from whom you purchase your high speed steels for their best advice in the light of your particular problem.

4. Take steps to obtain modern, efficient hardening equipment on the premise that regardless of the kind of high speed steel being hardened, proper hardening promotes better tool life, and better tool life in itself is a big step in conservation.

Forging — These steels can be forged like the tungsten type but at a slightly lower temperature. See Table II. When heating the molybdenum high speed steels for forging, they should be held in the furnace for the shortest time possible at the forging temperature.

Like all types of high speed steel, large pieces should be preheated to 1000 to 1200° F. before heating to the forging temperature.

Slightly oxidizing atmospheres are preferred when no protective coating is used. No protection is necessary for ordinary sized forgings unless long heating cycles are involved. Borax is a very effective coating but has the disadvantage of making the surface of the steel very slippery at the forging temperature, so the operator should take due precautions. To minimize the fluxing action on the furnace refractories, an excess of borax should be avoided.

After forging it is desirable to cool slowly to about 300° F. to avoid cracking from forging strains. This can be accomplished by furnace cooling or burying in lime, mica, or dry ashes, etc. Tools that have been forged should be machined or rough ground, after annealing, to remove possible surface defects and to reduce the amount of grinding after hardening.

Annealing — Like tungsten high speed steels, these steels should be annealed after forging and before hardening, or when re-hardening is required. Box annealing is always preferable. When annealing partially finished tools, and generally when surface protection is of prime importance, it is recommended that cast iron chips or other mild source of carbon be used for packing material.

Heat slowly and uniformly to the temperature given in Table II, soak thoroughly and then cool slowly in the furnace. The steel should not be taken from the furnace until it is below 1000° F.

Table II—Heat Treatment[1] of Molybdenum High Speed Steels

Operation	Type I*a* and I*b*, Molybdenum-Tungsten	Type II, Molybdenum-Vanadium	Type III, Tungsten-Molybdenum
Forging	1850-2000° F.	1850-2000° F.	1900-2050° F.
Not below	1600° F.	1600° F.	1600° F.
Annealing	1450-1550° F.	1450-1550° F.	1450-1550° F.
Strain relief	1150-1350° F.	1150-1350° F.	1150-1350° F.
Preheating	1250-1500° F.	1250-1500° F.	1250-1550° F.
Hardening[3]	2150-2250° F.[2]	2150-2250° F.	2175-2275° F.
Salt	2150-2225° F.	2150-2225° F.	2150-2250° F.
Tempering	950-1100° F.	950-1100° F.	950-1100° F.

[1]Hardening curves of the various types are appended.

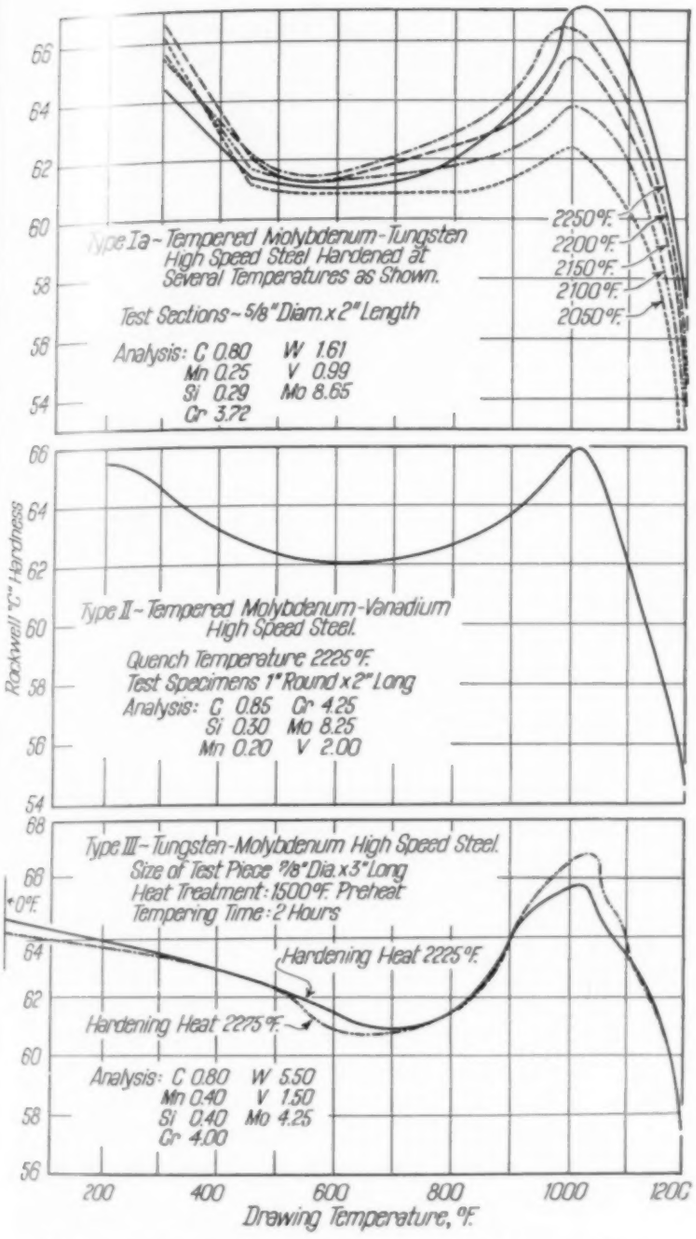
[2]Under similar conditions Type I*b* requires a slightly higher hardening heat than Type I*a*.

[3]The higher side of the hardening range should be used for the large sections and the lower side for the small sections.

After machining and before hardening it may be necessary to relieve harmful machining strains by annealing at 1150 to 1350° F.

Hardening — The general method of hardening molybdenum high speed steels resembles that followed with 18-4-1, but the hardening temperatures (noted in Table II) are lower, and more precautions must be taken to avoid decarburization especially on tools when made from Type I or II when the surface is not ground after hardening. Salt baths and atmosphere controlled furnaces represent an excellent type of equipment for hardening molybdenum high speed steel.

The use of coke fires or the blacksmith forge is not recommended for hardening any high speed steel, but if this type of equipment is all that is available, Type III may be so treated if an excess of air is avoided. However, simple surface protection in such equipment is


Type Ia - Tempered Molybdenum-Tungsten High Speed Steel Hardened at Several Temperatures as Shown.
Test Sections - 5/8" Diam. x 2" Length
Analysis: C 0.80 W 1.61
Mn 0.25 V 0.99
Si 0.29 Mo 8.65
Cr 3.72
2250°F.
2200°F.
2150°F.
2100°F.
2050°F.
Type II - Tempered Molybdenum-Vanadium High Speed Steel.
Quench Temperature 2225°F.
Test Specimens 1" Round x 2" Long
Analysis: C 0.85 Cr 4.25
Si 0.30 Mo 8.25
Mn 0.20 V 2.00
Type III - Tungsten-Molybdenum High Speed Steel.
Size of Test Piece 7/8" Dia. x 3" Long
Heat Treatment: 1500°F. Preheat
Tempering Time: 2 Hours
Hardening Heat 2225°F.
Hardening Heat 2275°F.
Analysis: C 0.80 W 5.50
Mn 0.40 V 1.50
Si 0.40 Mo 4.25
Cr 4.00
Rockwell "C" Hardness
Drawing Temperature, °F.

Surface Hardness of Small Sections of Molybdenum High Speed Steels After Quenching From Approved Temperatures and Then Tempering at Various Increasing Temperatures

safer practice even in the case of tungsten high speed steels.

The usual method is to preheat uniformly in a separate furnace to 1250 to 1550° F. and transfer to a high heat furnace maintained at the hardening temperatures (see Table II).

When heated in open fire or in furnaces without atmosphere control, these steels do not "sweat" like 18-4-1. Consequently, the proper time in the high heat chamber is a matter of experience. This time approximates that used with 18-4-1, although it is slightly longer when the lower part of the hardening range is used. Much can be learned by hardening preliminary test pieces and checking up on the hardness, fracture and structure. It is difficult to state exact heating times as this is affected by temperature, type of furnace, size and shape of tool, and furnace atmosphere.

Rate of heat transfer is most rapid in salt baths, and slowest in controlled atmosphere furnaces with high carbon monoxide content.

Quenching — Quench the tool in oil, air, or molten bath. To reduce the possibility of breakage and undue distortion in intricately shaped tools, it is advisable to quench in a molten bath at approximately 1100° F. The tool may be quenched in oil and removed while still red, or at approximately 1100° F. The tool is then cooled in air to room temperature and tempered immediately to avoid cracking.

Straightening — When straightening is necessary, it should be done after quenching and before cooling to room temperature prior to tempering.

Tempering — Reheat slowly and uniformly to 950 to 1100° F. For general work 1050° F. is most common. Hold at temperature at least one hour. Two hours is a better safe minimum and four hours is maximum. The time and temperature depend on the hardness and toughness required. Where tools are subjected to more or less shock, multiple temperings are suggested.

Salt Baths and *Furnaces* are described in the adjoining reports from committees appointed by the Office of Production Management.

Coatings — Borax may be applied by lightly sprinkling over the steel when heated to a low temperature (1200 to 1400° F.). Small tools heated as above may be rolled in a box of borax. Another method more suitable for finished tools is to apply the borax or boric acid in the form of a supersaturated water solution. In such cases the tools are immersed in the solution at 180 to 212° F., or it may be applied with a brush or spray. Pieces so treated are heated as usual, with care taken in the handling to insure good adherence.

Special protective coatings or paints when properly applied have been found extremely useful. They do not fuse or run at the tem-

peratures used and therefore do not affect the furnace hearth. When applying these coatings, it is necessary to have a surface free from scale or grease to insure good adherence. They may be sprayed or brushed on and usually one thin coat is sufficient. Heavy coats tend to pit the surface of the tool and in addition cause difficulty in its subsequent removal. Tools covered with these coatings should be allowed to dry before charging into the preheat furnace. After hardening and tempering the coating can be easily removed by light blasting with sand or steel shot. When tools are lightly ground, these coatings come off immediately.*

Special Suggestions — As in the case of tungsten high speed steels, tools with sharp corners, variable cross-sections, or very large sizes should not be given too drastic a quench in oil. It is better to remove the tool from the oil when cooled to or just below a red heat and allow it to cool in the air. Equalizing in lead or molten salt at about 1100° F. and then cooling in still air is good practice.

Single point cutting tools, in general, should be hardened at the upper end of the temperature range as given in Table II. Slight grain coarsening in such tools is not objectionable when they are properly supported in service and not subjected to chattering.

However, when such tools are used for intermittent cut, it is better to use the middle of the temperature range. All other cutting tools, such as drills, counter sinks, taps, milling cutters, reamers, broaches, and form tools, should be hardened in the middle of the range.

Certain applications requiring a maximum toughness (to resist shocks) will require the lower end of the hardening range. Examples are slender taps, cold punches, blanking and trimming dies.

The molybdenum high speed steels may be pack hardened following the same practice as used with tungsten high speed steels but keeping on the lower side of the hardening range (approximately 1850° F.).

Molybdenum high speed steels will take all the special surface treatments, including nitriding by immersion in molten cyanide, that are applied to tungsten high speed steels for certain applications.

*The trade names of these products that are known at present are as follows: "No-Carb", Park Chemical Co., 8074 Military Ave., Detroit, Mich.; "Sel-Car", National Copper Paint Co., 110 S. Dearborn St., Chicago, Ill., and "Ferritol", E. F. Houghton, Third, American & Somerset St., Philadelphia, Pa.

When borax and boric acid are used in a furnace with a silicon carbide bottom, it is necessary to use a metal pan (preferably of stainless iron) to prevent the borax from fusing with the silicon carbide. Such fusion produces a glass-like insoluble coating on the tool which is impossible to remove without damage to the cutting edge.

Salt Baths

By a special committee of O.P.M.:
A. F. Holden, Chairman
James McElgin
J. N. Bourg
W. J. Levy
J. Edward Donnellan, Secretary

Introduction — One of the contributing factors in the use and adoption of the molybdenum types of high speed steels as a substitute for the 18-4-1 has been the electric salt bath method for hardening.

Because molybdenum high speed steels decarburize when heated, the conventional-type furnaces are not satisfactory for hardening. The electric salt bath method, when properly controlled, eliminates this decarburization and is satisfactory for all types of molybdenum high speed steels.

Salt Bath Furnaces — In general, immersed electrode furnaces are being used where there is sufficient production to keep furnaces operating at a reasonable capacity. There are on the market today several types of immersed electrode salt bath furnaces and several types of salt baths. As a guide to those who are considering purchasing or installing such equipment, it is recommended that the selection of this equipment be made to suit their own production requirements from the equipment recommended.

The immersed electrodes generate heat directly in the molten salt bath itself by the electrical resistance of the bath material, and produce a positive circulation of the bath, due to the internal stirring action caused by the electrical flow between the electrodes. This

stirring action increases the speed of heating and eliminates local overheating, thus aiding close temperature control which is always advantageous. A properly selected and maintained salt bath prevents scaling or oxidation of the work, and also when properly controlled prevents surface decarburization.

Recommended Equipment

The following equipment is recommended for heavy production and constant use:

A three-pot unit consisting of

(a) Immersed electrode salt bath preheat furnace,

(b) Immersed electrode salt bath high heat furnace,

(c) Immersed electrode salt bath quench furnace.

(d) Optional: For extremely heavy production or large or intricate sections, two preheats are advantageous; the first to be operated at 1100-1300° F., and the second one at 1500-1600° F.

The following equipment is recommended for medium or light production, when it is to be used intermittently:

A three-pot unit consisting of

(a) Gas or oil heated salt bath preheat furnace,

(b) Immersed electrode salt bath high heat furnace, *(c)* Gas or oil heated salt bath quench furnace.

Salt Baths for Hardening — The manufacturers of salt baths (listed at end of this report) offer complete information on the method of use, as well as the method of chemical control, so that tools may be hardened free from any pitting or decarburization.

Decarburization or pitting in the high heat salt bath is usually caused by the presence of oxides. However, the manufacturers of salt baths supply a neutral bath containing a suitable deoxidizer or rectifier for the bath, which is sufficient to keep the bath free from oxides under normal operating conditions.

Under abnormal operating conditions, where a sufficient amount of new salt has not been added, it becomes necessary to make supplementary additions of rectifier material supplied by the manufacturer. The manufacturer will supply information as to procedure for simple chemical control to maintain the salt bath in a suitable condition.

When a refractory or brick lined pot is used there is less tendency for formation of oxides in the bath.

Procedure

For recommended temperatures for hardening in the salt baths refer to the O.P.M. Committee report on the heat treatment of molybdenum high speed steels [page 308]. Briefly, the procedure is as follows:

A. Clean work free from scale, rust, oil, grease and moisture. Use either solvent degreaser or suitable alkaline cleaner, followed by a clean hot water rinse, and thorough drying. Every precaution must be taken to prevent moisture on tools going into the salt, as wet tools may cause a steam explosion, burning the operator.

B. Immerse in preheat salt bath at 1500-1550° F. Allow sufficient time for work to reach temperature of bath.

C. Transfer to high heat salt bath. Temperature 2150-2250° F. Allow sufficient time for work to reach temperature of bath, plus proper soaking time at temperature. [Refer to the heat treating practice on preceding pages.]

D. Transfer to quench bath, temperature 1100-1200° F. Allow sufficient time to cool to bath temperature. Two to five minutes will suffice, depending upon size. Remove from salt bath and cool in air or oil. Quenching in oil is not recommended for work of intricate design or work where distortion is apt to occur.

E. After work has cooled to *room temperature,* wash off all adhering salts in a hot alkaline cleaner. If the work is to be tempered in a furnace (air atmosphere), the work should be shot blasted, sand blasted, or cleaned by other methods, to insure removal of all adhering salts. If this is not done, the salt will attack the work during the tempering. If a salt bath is used for tempering, the work need only be cleaned in a hot alkaline solution or hot water.

F. For tempering, see the practice by the

O.P.M. Committee on the heat treatment of molybdenum high speed steels [page 307 *e.s.*].

Effect of Salt Bath Hardening — Steels when hardened in salt baths are entirely surrounded by neutral molten salt. A salt film is retained on the tool throughout the hardening procedure, thus preventing decarburization or scaling.

The salt bath hardening method provides uniform heating, and this generally results in less distortion. All sections of intricately shaped tools are uniformly heated by this method. The salt bath permits selective hardening.

When a salt bath is properly selected and properly maintained, there is no chemical attack by this bath on the molybdenum high speed steels. The original surface of the steel is retained.

Molybdenum high speed steels will take all the special surface treatments, including nitriding when immersed in molten cyanide, that are applied to tungsten high speed steels for certain applications.

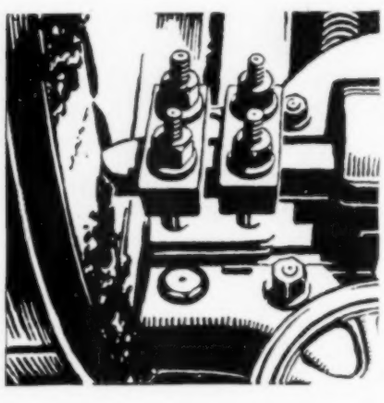
Manufacturers

There are many installations of salt bath furnaces now in use for hardening molybdenum high speed steels. The manufacturers of salts and salt bath furnaces listed below are qualified by experience to give complete engineering service:

Electrode Salt Bath Furnace Manufacturers — Ajax Electric Co., Philadelphia, Pa.; Bellis Heat Treating Co., Branford, Conn.; Commerce Pattern Foundry & Machine Co., Detroit, Mich.; The A. F. Holden Co., New Haven, Conn.

High Speed Salt Bath Manufacturers — Bellis Heat Treating Co., Branford, Conn.; The A. F. Holden Co., New Haven, Conn.; The E. F. Houghton Co., Philadelphia, Pa.; Park Chemical Co., Detroit, Mich.

Gas-Fired or Oil-Fired Pot Furnace Manufacturers — Any furnace manufacturer producing pot furnaces, of which there are approximately 25.



Controlled Atmosphere Furnaces

By a special committee of O.P.M.:
C. I. Hayes, Chairman
P. B. Crocker
W. M. Hepburn
Norbert Koebel
Karl Ness
J. Edward Donnellan, Secretary

Introduction — Molybdenum high speed steels have a tendency to develop a soft surface when heated to the hardening temperatures. Because of this tendency, it is necessary and important to exercise certain well established precautions to protect the surface of these toolsteels.

In addition to the application of protective coatings when conventional type furnaces are used, and also the use of high temperature salt baths, atmosphere controlled furnaces satisfy this demand for surface protection against attack. These furnaces are now available in both electric and fuel-fired types where the atmosphere is independent of the source of heat. This permits control of the atmosphere in contact with the work to be treated. Small and delicate pieces can be given the heat treatment that will develop the good properties of the steel without injuring the surface or overheating thin projections.

The ideal atmosphere is one that is not harmful to the steel. The atmospheres commonly used are *(a)* products of combustion and *(b)* inert gases, both of which have been cleaned of undesirable constituents and closely regulated as to composition.

The manufacturers of atmosphere controlled furnaces that are in general use for the hardening of molybdenum high speed steels are listed in this report. In each case, it is claimed by the manufacturer that these furnaces, when properly operated, have proven satisfactory in eliminating decarburization or other harmful attacks in the heat treatment of molybdenum high speed steels.

Characteristics of Atmospheres

An atmosphere for the successful heat treatment of molybdenum high speed steels must be *(a)* capable of preventing decarburization; *(b)* capable of preventing excessive carburization which will cause wrinkling of the surface, melting of the edges, pitting, and embrittlement of the cutting edge; and *(c)* capable of preventing harmful scale or oxidation.

Preheat — To prevent the above changes from taking place, the atmosphere for the preheat temperature is just as important as the atmosphere for the high heat temperature. The atmosphere for the preheat temperature should have the same characteristics as the atmosphere for the high heat temperature. A high heat furnace equipped with an atmosphere for satisfactory hardening will be of no value if the proper atmosphere is not used on the preheat furnace.

High Heat — As any one of several atmosphere control methods may be used, no general recommendations can be made regarding settings and methods of operation, but competent engineering service should be supplied by the furnace manufacturers. Complete operating information should always be given by the service engineers after the furnaces are installed.

Manufacturers

In the selection of atmosphere controlled furnaces, the purchaser should secure a guarantee that the furnace selected will satisfactorily harden molybdenum high speed steels for his particular needs without the use of surface coating materials.

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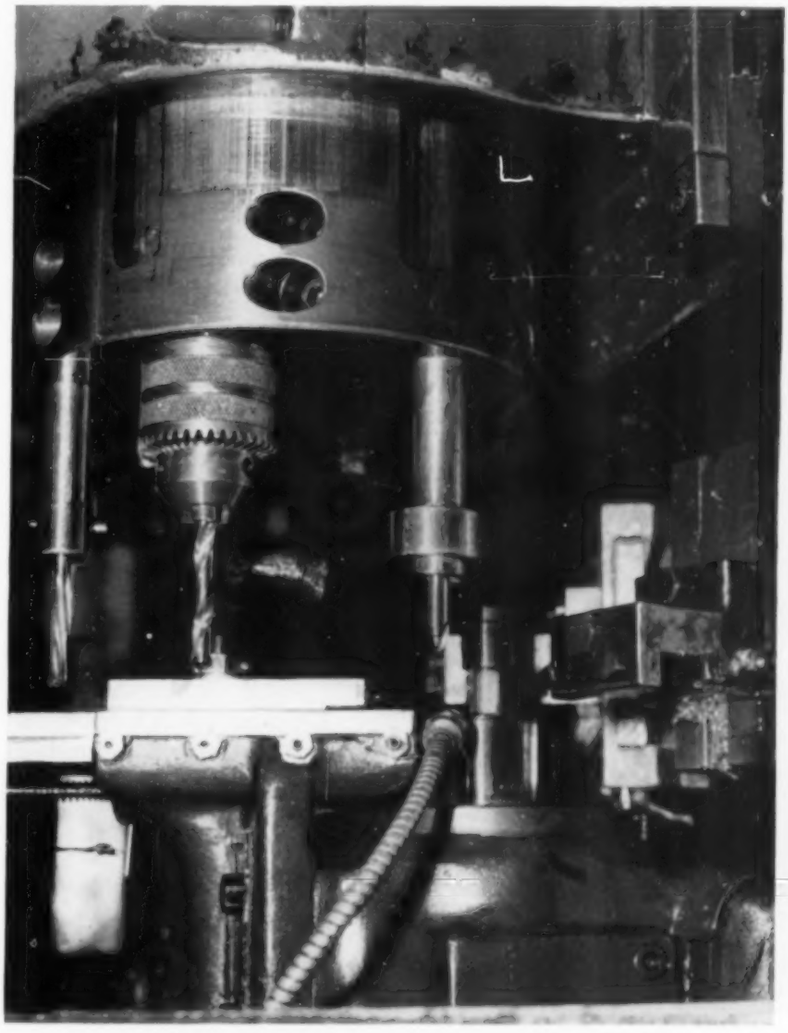
*The following manufacturers of conventional type furnaces use the Sentry Co. method for atmosphere control: American Electric Furnace Co., 27 Von Hillern St., Boston, Mass.; American Gas Furnace Co., Elizabeth, N. J.; Barkling Fuel Engineering Co., 402 No. Paulina St., Chicago, Ill.; Charles A. Hones, Inc., Baldwin, L. I., New York; and Dempsey Industrial Furnace Corp., Springfield, Mass.

The following firms are manufacturers of controlled atmosphere furnaces and upon request will supply bulletins and complete descriptions of their equipment:

General Electric Co., 1 River Road, Schenectady, N. Y.; C. I. Hayes, Inc., 75 Baker St., Providence, R. I.; Hevi Duty Electric Co., 4212 West Highland Ave., Milwaukee, Wis.; Lindberg Engineering Co., 221 No. Laflin St., Chicago, Ill.; The Sentry Co.,* Foxboro, Mass.; Surface Combustion Corp., 2375 Dorr St., Toledo, Ohio.

These firms will also supply references of those who are successfully hardening molybdenum high speed steels in their controlled atmosphere furnaces. They also extend engineering and metallurgical assistance to furnace users as well as heat treat samples or permit those interested to heat treat their own samples in the respective equipment which is under consideration.



High Speed Tools in Douglas Aircraft Co.'s Plant

IN MEMORIAM

GEORGE K. BURGESS

1874 — 1932

PHYSICIST AND METALLURGIST

PAST PRESIDENT
AMERICAN SOCIETY FOR STEEL TREATING

CHARTER MEMBER
WASHINGTON CHAPTER A.S.S.T.

PRESENTED BY
WASHINGTON CHAPTER A.S.S.T.
MCMXXXIII

Washington Chapter ⊜ has instituted an annual meeting to honor the memory of the late George K. Burgess, who in his lifetime was president ⊜, A.I.M.E., A.S.T.M., Washington Academy, and Washington Philosophical Society. He was chief of the Division of Metallurgy, becoming Director of the National Bureau of Standards

George Kimball Burgess

1874-1932

THOSE OF YOU who knew GEORGE BURGESS are, I know, greatly pleased that a memorial has been established in tribute to him and to his lifelong service to the Bureau of Standards. And you will also agree that no more fitting form for this memorial could be employed than that of an annual lecture, which through the years, in conformity with the times, can continue to bear evidence of the sound conception and framework which he gave to the metallurgical work of the Bureau and to the inspiration his personal contact lent to it.

I feel particularly honored at being called to deliver the first of these lectures "On the Art of Alloy Engineering", although I fear that my principal, perhaps my only, qualification for that honor is the great debt I personally owe Doctor BURGESS for the guidance and inspiration which contact with him in those early years gave to me. At such a time as this, one is naturally filled with personal reminiscences — I recall him so vividly, his alert personality, his keen sense of humor, his wide interest in matters both professional and cultural, and the friendliness and helpfulness of his manner of administration.

GEORGE KIMBALL BURGESS was always the leader, never the mere director!

The personal gifts which he brought to his work were many and charming. Of his professional gifts, which were many, I have always reckoned as the most significant that happy combination in him of the constant sense and urge of the practical in research, coupled with that passion for accuracy which was partly the heritage of his training in physics, and 10-year service to the Bureau as physicist. His objectives were always constructive and of good sense, but the means to those objectives had always to conform to the highest standards of scientific accuracy. No group of research workers could have had a happier and more stimulating leader than did we in Division Eight (Metallurgy) — nor one which had a leader who was more unselfish in creating opportunities for his staff in research and publication.

Before going to the main subject of my discourse [to be published next month in METAL PROGRESS] I would like to make some observations on the research interests of Doctor BURGESS and their far-reaching influence on today's technology.

His happy combination of a sense for the practical and a passion for accuracy are well

Preliminary remarks to first
Burgess Memorial Award Lecture

By Paul D. Merica
Vice-President
International Nickel Co., Inc.

illustrated in the research subjects in which, as chief of the newly created Division of Metallurgy, he took keen personal interest. Foremost amongst these was certainly his interest in pyrometry. At a time when the industrial use of pyrometry was yet in its infancy, and many of its modern techniques were yet unborn, he saw clearly the significance which this art was to have for metallurgy. He devoted much personal attention to its development in many directions — the establishment of pyrometric standards, the development of new types of pyrometers such as the micro-pyrometer, the adaptation of optical and other pyrometers to practical uses in steel and other plants. And in his public utterances, he always preached the lesson of the value of pyrometry to the economy and productivity of metallurgy.

How pregnant of later development this early interest of his is now a matter of common knowledge. Whereas at the time of which I speak — the years 1912 to 1920 — the pyrometer was at best a laboratory instrument in metallurgical industry, often having to be almost furtively introduced into the plant, it is now a necessary fixture. Important as this quite extraordinary growth of the metallurgical use of the pyrometer has been, it by no means measures adequately the significance of those important corollary developments of today, which collectively have arisen from the growing consciousness of the economic value of accurate temperature measurement.

For temperature control, temperature cycle control, then atmosphere control, and finally the modern temperature controlled electric or fuel-fired furnace for heat treating metal are all natural developments of pyrometry consciousness. And there is no development in metallurgical art more spectacular, both in performance and in extent of use, than the cycle and atmosphere controlled heating furnace of today, in comparison with the simple, manually controlled, heat treating furnace of 25 years ago — and I mean *manually!* Within this short period of time, powerfully impelled by mounting recognition of the benefits of pyrometric control, we have emerged from an era in which metallurgical heating operations were conducted in furnaces in which both time and space fluctuations of temperatures were considerable, and always at the mercy of an artist of most uncertain abilities. Today, an important new industrial furnace industry has arisen, which designs and produces hundreds of large heating furnaces every year; in them space and time temperature variations may be controlled within 5° F., and in a substantial proportion of them close atmosphere control is likewise available.

A host of impressive accounts could be given by the various metallurgical industries of the significance to them of modern furnace control. I cite a comparatively simple one from my own experience: Some 20 years ago Monel and nickel sheets were annealed in cast steel boxes. The weight of the box and cover was often greater than that of the sheets, and the complete annealing cycle required approximately 72 hr. Each sheet in the box had to be covered with a thin layer of finely ground charcoal, out of which practice several undesirable consequences flowed.

Today such sheets are annealed in a continuous, gas-fired, temperature controlled furnace, some 170 ft. long, in which the sheets are heated and cooled in a controlled, reducing atmosphere — the complete cycle requiring only 7 min.! Not only is the cost of annealing in such equipment much less than before but, what is more important, the modern method produces sheet of much more uniform quality in temper, grain size, and surface. And be it noted that pyrometric control is essential to the success of this method, since the actual annealing is completed in about 3 min., at a temperature of which undue variation would definitely substantially over-anneal or under-anneal the product.

I venture to say that if it were possible to inventory all of the economies and the enhancements in value which result currently from those improvements in metallurgical equipment and technique, arising reasonably directly out of mounting pyrometry consciousness, we should find them most impressive indeed. Review in your minds the economic value of our close control of heat treating operations in automotive steels today — of our bright annealing of steel and brass mill products! George Burgess saw values and paths very clearly!

It would be instructive to follow similarly, the later course of constructive development of other early research interests of Doctor Burgess, such as his studies of sound ingot production, the attention he gave to the effects and to the elimination of gases in steel and metals, his interest in the performance of railroad materials and types of failure. A list of these would in itself form a most stimulating outline for any lecture on progress in metallurgy.

Correspondence

American Silver Producers' Research Project

BRIDGEPORT, CONN.

To the Readers of METAL PROGRESS:

The American Silver Producers' Research Project, sponsored by several of the leading silver producing companies in the United States, was reorganized June 1, 1940 and the research program and activities were transferred to the laboratories of Handy & Harman, where it has completed a year of activity. The Project was formerly located at the National Bureau of Standards, and extended notice of its activities and achievements has been given by METAL PROGRESS from time to time.

The field of electroplated coatings continues to show promise as an outlet for silver, and the pilot plating plant has been kept busy on sample drums, pails and cans. At the present time one of the large can manufacturers is cooperating with the Project and a chemical supply house in the development of a silver lined can for packaging chemicals. This work, still in the early stages, is progressing satisfactorily and shows promise. Containers with a silver plated coating also have been packed with different commodities and some experimental units have been put into service, with various results. It has not yet been determined why some containers have been quite satisfactory while the contained substances have been contaminated in others.

One of the criticisms of silver lined containers appears to be that they do not give sufficiently superior advantages over those now in use to warrant the additional cost. For the general run of containers this is undoubtedly the case, but it is not true for packaging some specialized products. In some instances silver lined containers are being seriously considered and tested for packaging corrosive materials because the corrosion resistance of other metals and lacquers is not adequate.

In recent months the scarcity of many base metals has focused attention on the use of silver as a substitute for aluminum, nickel and tin. In places where sheet or foil aluminum has been used for its corrosion resistance or high reflectivity, it is apparent that silver plating on available metals can be substituted since it possesses these qualities, for most purposes, to an even better degree than aluminum. Silver electrodeposits are being studied as a substitute for nickel, as an undercoating for chromium plating. A series of experiments is under way to determine what advantages may be derived from the use of a corrosion resistant electroplate of silver, followed by a hard, wear resistant chromium deposit. It is hoped that the two metals, aluminum and nickel, badly needed for national defense, which are used in refrigerator shelves, ice cube trays, toasters, waffle irons and others, can be replaced at least in part by silver.

The project has also conducted experiments to determine the strength of extruded tubing made from a 3.5% silver, 96.5% tin alloy. A bursting strength of 2500 psi., or almost double that of pure tin, was obtained and this is apparently far in excess of any working pressure encountered in distilled water lines where this material is finding commercial use. Tests on threaded joints showed that the alloy had a tensile strength 25% greater than joints made with pure tin tubing. (For certain installations it would seem feasible to use threaded connections in distilled water lines if the tubing were made of the silver-tin alloy.)

Both the 3.5% silver and 5% silver-tin alloys are finding applications as solders. Interest continues in the possibilities of using lead-silver solders in place of the standard lead-tin alloys in automatic can making machines. There are many reasons for this and important among them is the fact that a large saving in the use of the strategic metal tin would result. The 2½% silver-lead alloy is cheaper than the standard 50-50 solder and joints equally as satisfactory can be obtained. Many of the larger can manufacturers are experimenting with these alloys to obtain data on actual operating conditions and service tests.

[EDITOR'S NOTE — The utility of silver as a major alloying element for the common metals was studied early in the Project's life at the Bureau of Standards with disappointing results. A recent development of the greatest interest, however, is the strong extruding alloy of magnesium containing 6% silver.]

The Silver Project's Fellowship at Lehigh University has continued the corrosion studies. Tests include not only a study of different chemicals but also a study of a large number of different commercial products which may be manufactured in silver equipment or packaged in silver containers.

More recently a study has been started on the corrosion of silver-to-silver joints made with different silver brazing alloys. This is of particular interest in connection with the manufacture of silver lined chemical equipment. All of this work has been carried on in a thorough and comprehensive manner and many valuable data have been obtained. Prospective users are invited to avail themselves of it.

ROBERT H. LEACH
Vice-President
Handy & Harman

Welded Ships Save One-Fifth

CLEVELAND, OHIO

To the Readers of METAL PROGRESS:

A recent statement from the United States Maritime Commission about the savings in steel effected by modern designs and methods of ship building makes a better case for welded ship construction than would probably be claimed by welding engineers. The Commission's statement follows, in part:

"Saving of more than a half-million tons of steel is the contribution of modern ship designing and construction to the Maritime Commission's tremendous shipbuilding program now under way. That is the amount of steel that is being conserved in the construction of 705 Commission-designed ships by introduction and employment of methods not known in the first World War, when this country made its last great shipbuilding effort.

"If the 705 merchant ships were built under World War conditions 2,775,000 short tons of steel would have been required. But today, under the most modern methods, they will require about 2,196,000 short tons.

"Since the last war, naval architects have been on the alert for any chance to save weight in the construction of ships. Any saving in steel means less steel to buy, less material to handle, greater cargo-carrying capacity, and more economy in operation.

"The greatest single weight saving advance has been the introduction of welding. This has so replaced riveting that, today, entire ships are being turned out without a single rivet."

On the basis of these figures, 579,000 tons of steel are saved, or 21% of the weight of the equivalent ships of 1916-1918. On the average, the 705 ships now under construction require 3100 tons of steel, so the saving over the 1918 ship would amount to enough steel for 186 addi-

Typical Examples of Ship Steel Saved by Welded Construction

VESSEL	TYPE OF VESSEL	YARD WHERE BUILT	LENGTH	STEEL SAVED
Dolomite I	Freighter	Dolomite Marine Corp., Rochester, N. Y.	214 ft.	25%
Algoma	Tugboat	Sturgeon Bay Shipbuilding & Dry Dock Co., Sturgeon Bay, Wis.	45	10%
Dam Yank	Towboat	Sturgeon Bay Shipbuilding & Dry Dock Co., Sturgeon Bay, Wis.	165	7½%
Norfolk	Freighter	Great Lakes Engineering Works, River Rouge, Mich.	300	16%
Patty Nolan	Tugboat	Merritt-Chapman & Scott Corp., New York, N. Y.	45	25%
Studerus	Tanker	United Dry Docks Co., Brooklyn, N. Y.	64.5	20%
Lewis	Tugboat	Hanson Marine Ways, Galveston, Texas	55	15%
Betty H	Tugboat	Eliot Shipyard, Houston, Texas	70	15%
....	Tanker	Federal Shipbuilding & Dry Dock Co., Kearny, N. J.	450	10%

tional vessels, which moving together would carry about 2,000,000 tons of cargo each trip.

From our own extensive files on welding, the James F. Lincoln Arc Welding Foundation is able to cite typical examples showing steel savings in ship construction ranging from 7½% to 25%, and averaging 15.9% over riveting. Thus the figures from the Maritime Commission represent a further advance in weight saving, mostly due to the capabilities of the welding method. It should be noted that there is no countervailing penalty in extra time of construction; welded ships are made in substantially less time than riveted ones.

Typical examples of weight saving from American shipbuilding practice in recent years are contained in the attached tabulation.

ED C. POWERS
Assistant Secretary
James F. Lincoln Arc Welding Foundation

Moderate Cold Work increases endurance limit

INDIANAPOLIS, IND.

To the Readers of METAL PROGRESS:

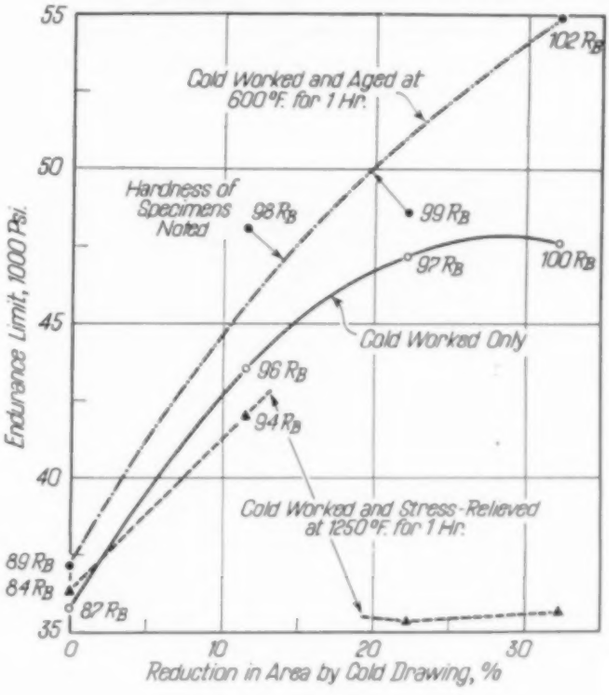
It is a fairly widespread impression in the forging industry that "coining" of forgings, or light cold working to size, will measurably increase the fatigue resistance of the coined pieces. On the other hand, some people think that any effect would be limited strictly to the surface layers. It may be of general interest to present some data applicable to this situation acquired during the author's post-graduate work at the University of Wisconsin under the guidance of Prof. JOSEPH F. OESTERLE.

A study was made of a single long bar of S.A.E. 1035 steel, so chosen because it is used in large quantities by the forging industry. It was cut into five pieces; one length was used as hot rolled ($1\frac{1}{16}$ in. dia.). Three other portions were drawn to 1 in., $\frac{15}{16}$ in., and $\frac{7}{8}$ in. dia. (respectively 11.5, 22.2 and 32.2% draft). The fifth piece broke on attempting to draw it to $\frac{13}{16}$ in. This work was done by Wyckoff Drawn Steel Co. through the kindness of ANGUS G. STURROCK.

Twenty-four standard fatigue specimens for the R. R. Moore machine were cut axially from each of the four bars; eight were tested as was; eight were aged at 600° F. for 1 hr. before testing; and eight were stress-relieved 1 hr. at 1250° F. This heat treating was done by VERLE H. ERICKSON at Snap-On Tool Corp.

The attached diagram gives the results of endurance tests run to 10 million cycles (well beyond the "knee" of the S-N curve in all cases). It may be concluded that cold working in the neighborhood of 28% draft (reduction in cross-section) gives the best endurance limit for plain 0.35% carbon steel. A considerable scatter in the results at these heavy drafts indicates, however, that the limit of safe drawing has been reached and that there may already be incipient cracks present in the samples. Aging at 600° F. not only increases the endurance limit but also makes the material more uniform in its testing behavior. At 1250° F. rapid recrystallization sets in after cold working somewhere between 12½ and 21% draft, and the endurance resistance of such recrystallized material is no higher than that of the as-rolled bar.

Cold Drawing up to the Verge of Over-Draft, With or Without Aging, Increases the Endurance Limit of S.A.E. 1035 Steel



The results of this study indicate, therefore, that the endurance limit of forgings of medium carbon steel can be increased up to 25% by appropriate cold work, with or without subsequent aging at 600° F. However, the slight cold work involved in many coining operations would apparently have very little influence.

THOMAS G. HARVEY
Metallurgical Engineer
Monarch Steel Co.

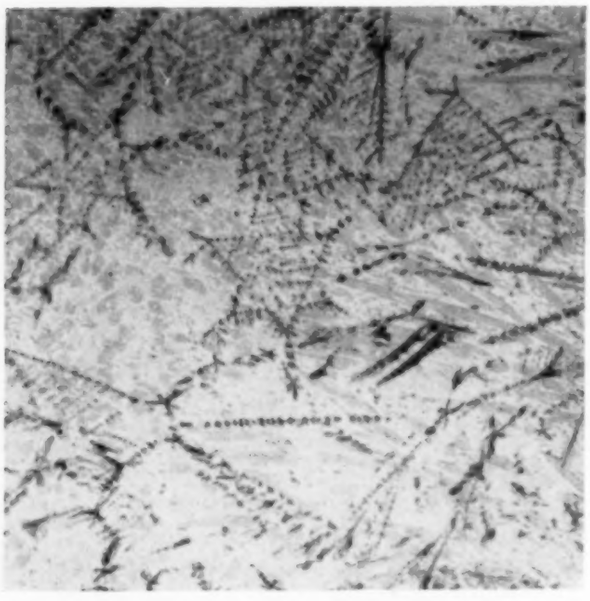
Star Gazing

ENILOM, USONIA

To the Editor of METAL PROGRESS:

The true scientist should be interested only in facts, in truth. But a man in the august position of Editor of METAL PROGRESS should also be discreet, should recognize the political angles. Consequently it is disappointing to find your pages used for propagation of propaganda.

When the New Order comes to this country, when Aryan enlightenment reaches us, Meinherren GOEBBELS and HIMMLER will demand an accounting from you as to why you permitted yourself to be used as a tool of the Jewish international bankers and President ROSENFELT.



Cast Alloy Steel; 0.85% C, 12.0% Cr, 3.5% Ni, 1.0% Mo. Quenched in oil from 2200° F., drawn at 1340° F. Polished and etched with Murikami reagent. Magnified 100 ×

I refer not only to the several times the Editor's apparent decadence led him to make remarks in support of democracy, nor to the vicious chart he once published showing what problems would be settled by the Great Crusade, but most specifically to the photomicrograph on page 56 of the July issue of the capitalistic METAL PROGRESS.

A really competent censor would have instantly recognized the Zionist symbol, the Star of David. How thoroughly the forces of resistance to the New Order have infiltrated! Even the molecules in their mysterious motions are harnessed to the subtle work of the deluded foes of the Wave of the Future.

This contamination of our metals has been going on entirely too long. It must be stopped. I discovered it only the other day in another enlarged view of metal, authoritatively said to have been photographed in the Krupp laboratories in Essen, Germany, in 1935. Nevertheless it contains the same subversive sign. Since that time that laboratory, I know, has been purged of such non-Aryan personages as BENNO STRAUSS, co-discoverer of the stainless steel known as 18-8, so doubtless such metallic arrangements will never appear again.

METALLURGICUS

P.S. Could it have been due to the Japanese reagent?

Corrosion of Ordnance and Munitions

UGINE, SAVOIE, FRANCE

To the Readers of METAL PROGRESS:

The length of service or useful life of a part, a machine or a metallic structure depends both on its mechanical strength and what may be termed its chemical strength. Mechanical strength is resistance to alteration by wear, by abrasion, by deformation, resistance to rupture by impact (toughness) or by fatigue (endurance). In a similar sense, chemical strength is resistance to the chemical action of the surrounding medium, or resistance to corrosion up to a limit which may depend on the amount of change permissible in the surrounding medium (for example, machinery in a chemical plant), or in the exterior appearance (for example, decorative parts), or in the tightness (piping and vessels, for instance), or in the mechanical strength (the general case of the wasting away of the body of structural members). This chemical strength depends on the metal, its prior treatment and maintenance, and the condition of the surface.

Alteration by chemical corrosion may act in conjunction with mechanical stress but occurs constantly in the absence of the latter — that is, in machines not being used and parts in the warehouse or in stock. That is what causes the difference between manufacture of munitions and ordnance in time of war and in the happier times of peace.

In general, a metal (and its surface condition) is chosen in such a way that the useful

chemical life shall be longer than the useful mechanical life, the length of service of the part thus being dependent solely on its mechanical strength.

In times of peace, artillery and ammunition must have maximum longevity compatible with reasonable cost, so that corrosion resistance may become the primary consideration in the choice of materials which are held in arsenals and not immediately used.

In times of war, on the other hand, length of service is not conditioned by corrosion but by the use to which the materials are put. This period of service, as for instance with aeronautical materials, may be relatively short; often it is determined by the life of the motor. Likewise, the useful life of a projectile is extremely short. Availability of raw materials replaces cost as the first consideration; furthermore, appearance is usually immaterial.

Manufacturing tolerances should also be revised in war time, and limits may properly be adopted to speed production which are unacceptable in times of peace.

Let us consider a few examples.

In a hydroplane, it is important that certain parts, necessarily made of light alloys because of the fundamental requirement of light weight, be highly resistant to marine corrosion in peace time. Hence the choice of special corrosion resistant alloys and processes for corrosion protection. In war time these considerations lose their importance.

A cartridge case manufactured in peace time must be capable of long storage without chemical alteration; hence the use of alpha brass of 67 to 70% copper, likewise recommended for ease of forging and of repair for re-use. In war time the factor of copper supply, together with the rapid consumption of munitions, tends toward the use of steel or aluminum for cartridge and shell cases, and protective measures are chosen sufficient for the brief chemical life required. (It should be recalled that the substitution of steel for copper and brass was experimented with at the time of the last war for cartridge and shell cases, cartridge belts and various small parts of fuzes. Steel link belts are, I understand, now standard in your country for machine gun ammunition.)

Shell fuzes are likewise made largely of brass, either of a type which can be forged or one which can be cut, in such a way as to combine mechanical workability and durability of manufactured parts. For the same reason of copper supply, there is a trend toward the use of zinc-base alloys (or aluminum) already experimented with in the previous war. Progress since made in pressure die casting, and the present purity of industrial zincs, offers improved fabricating facilities together with improved resistance to corrosion.

As to rifles and side arms, rapid burnishing processes offer sufficient protection for the length of service.

Protective processes for magnesium which would be considered insufficient in peace time are also acceptable in war time.

In other words, it is superfluous to endow a part with much greater corrosion resistance than the average life of the apparatus.

Likewise requirements of purity — particularly the absence of lead in metals such as steel and tin which must be in contact with nitrate explosives of the picric acid and similar types — become less necessary as the time of contact is reduced.

Thus, many of the exigencies of manufacture imposed by the possibilities of corrosion during storage in peace time disappear in the course of war. Two types of manufacture should therefore be foreseen, for war and for peace, differing particularly in the choice of materials and surface protection, and determined by considerations of corrosion, manufacturing cost and material supplies. They may be entirely dissimilar under the two circumstances.

ALBERT M. PORTEVIN
Consulting Metallurgist
Bessemer Medalist

Impact and Hardness Tests

COVENTRY, ENGLAND

To the Readers of METAL PROGRESS:

The following supplementary notes to GORDON T. WILLIAMS' article on "Impact and Hardness Tests" may be of interest:

Over here the Izod test (incidentally also mispronounced as in the United States) is more popular for routine tests than the Charpy. General practice, where a large number of tests are being made, is to use the round form of specimen with three milled notches as covered by the British Standard Specification 133 of 1933, and 2.A.4. (Aircraft Materials). Conflicting opinions are expressed on the comparability of the figures obtained with the round and square

specimens, but the writer has made numerous tests on these two forms of specimens, and so far has not observed any appreciable discrepancy between the figures obtained for the usual automobile steels.

Probably one of the most valuable uses of the impact or notched-bar test not mentioned in the article is in the investigation of temper brittleness. It appears to be far more sensitive than any other practical form of test in the determination of the susceptibility of steels to this undesirable condition.

The Vickers hardness testing machine is in general laboratory use in Britain, and is the accepted standard test, although Brinell and Rockwell machines are used for routine tests, and the Scleroscope is used to a limited extent. Several types of machines are becoming popular which work on the Brinell principle, but give a projection of the impression on a screen equipped with a measuring device.

R. J. Brown
Chemist and Metallurgist
Morris Motors, Ltd.
Engines Branch

[Editor's Note — Evidently the Luftwaffe failed to Coventryize Morris Motors, or else Morris Motors landed on its feet!]

Wear and Scuffing of cylinder bore irons

Darlaston, Staffs., England

To the Readers of Metal Progress:

"Cylinder bore wear is just about in a class with politics and religion, for it is one of the most controversial subjects which engineers can argue, the reason being that there is so little real fundamental engineering data available." This statement is due to Max Roensch of the Chrysler Corp., and if it is true no further excuse is needed for making another contribution to the already extensive literature on this subject.

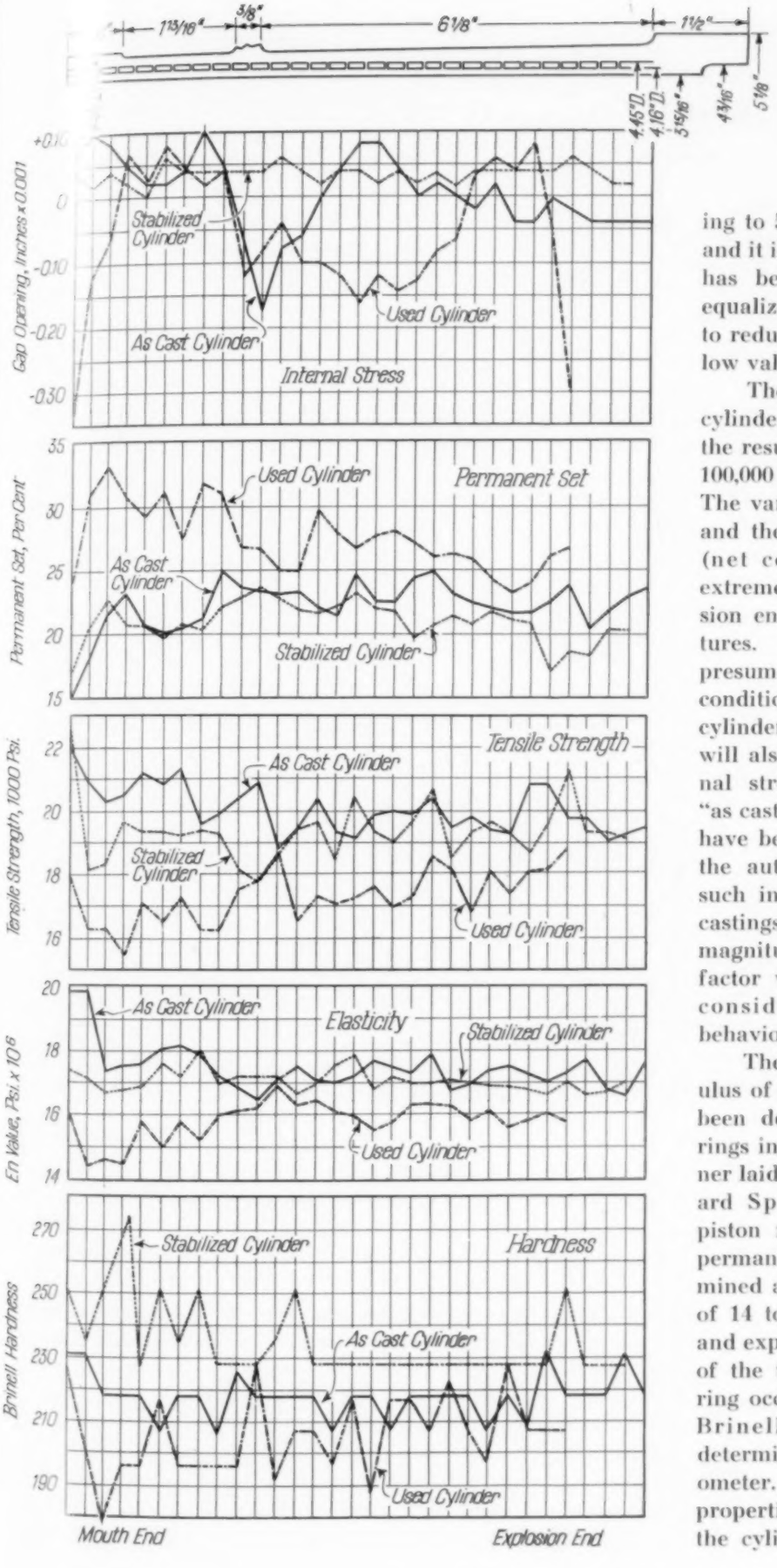
The very interesting notes and investigations by Paul S. Lane on this subject which appeared in the March issue of Metal Progress draw attention to the importance of the structure of cast iron on its behavior under wear conditions. They show also the possibility of wide variations in the structural character of cast iron taken from various portions of a cast iron monobloc cylinder. Other workers in this same field have also emphasized the importance of the structure. While it is agreed that this is of importance, in view of the nature of wear in internal combustion engine cylinders, these observations on structure ought not to distract attention from the actual mechanical properties of the material constituting the cylinder block.

It is possible to determine the nature of the various mechanical properties in cylinder block material. The following interesting example is taken from a study of this type in connection with three sand cast monobloc castings of the type used for commercial vehicle engines. The castings were all made in dry sand molds with oil sand cores. One was tested "as cast", one was tested after stress relief anneal (stabilized) and one was taken from an engine after 100,000 miles running. The composition of the castings examined was as follows:

Element	As Cast	Stabilized	Used
Total carbon	3.06%	3.28%	3.25%
Combined carbon	0.66	0.80	0.65
Graphite	2.40	2.48	2.60
Silicon	1.56	1.60	1.77
Manganese	0.78	0.95	0.94
Phosphorus	0.36	0.37	0.64
Chromium	0.11	0.23	....

In each case one barrel was detached by machining from the six cylinder monobloc castings. The barrel thus detached was machined to an internal diameter corresponding to the bore of the finished cylinder, and then machined externally and parted off into adjacent rings of a uniform radial thickness of 0.14 in., and length of $\frac{3}{16}$ in. In the case of the used cylinder the test rings parted off were machined to the same outside diameter and radial thickness, but the used surface of the bore was left untouched. The adjoining diagrams show the variation in the properties from the mouth end to the explosion end in each of the cylinders examined. The properties dealt with are the tensile strength, the modulus of elasticity (EN value), the Brinell hardness, permanent set and internal stress values. Each of the diagrams reveals interesting variations.

In the case of internal stress as revealed by the gap movement when the ring was sawed apart at one element, this varies in the "as cast" specimen from a positive value (gap opening) at the mouth end, passing through a negative value (gap closing) in the neighborhood of the junction of the barrel with the bottom portion of the water jacket, passing again to a positive value and then to a negative value at the explosion end. Results for the stabilized cylinder were taken from the corresponding barrel of another monobloc casting after submitting to a low temperature stabilizing treatment by heat-



Variation in Properties of Cylinder Bore Iron, Cast Monobloc, as Determined on a Series of 3/16-In. Rings, 0.14 In. Thick, Machined From Metal Adjoining the Inner Bore

ing to 550° C. (1025° F.) for 3 hr., and it is obvious that the treatment has been sufficient not only to equalize the internal stresses, but to reduce them to a comparatively low value.

The example from the worn cylinder is interesting as it shows the results in a cylinder bore after 100,000 miles service in an engine. The variation in sign of the stress and the very high negative value (net compression) at both the extreme mouth end and the explosion end are the outstanding features. An effect which will be presumed to be due to the cooling conditions at the junction of the cylinder barrel and water jacket will also be observed in the internal stress measurements on the "as cast" cylinder. Such variations have been observed frequently by the author and the existence of such internal stresses in cylinder castings and the variations in their magnitude and distribution is a factor which must be taken into consideration in studying the behavior of engine cylinders.

The tensile strength and modulus of elasticity (EN value) have been determined on the annular rings in accordance with the manner laid down in the British Standard Specification No. 5004 for piston ring drum material. The permanent set values were determined at an arbitrary stress value of 14 tons per sq.in. (31,360 psi.) and express the set as a percentage of the total deflection of the test ring occurring at this stress. The Brinell hardness figures were determined with the Firth hardometer. Variations in each of the properties at various positions in the cylinder bore are of interest,

and such variations must be expected to have an influence on the behavior of both the cylinder and piston rings during service.

Investigations of this nature have proved of very great value in examining both engine cylinder and piston ring failures.

JAMES E. HURST, D. Met.
Bradley & Foster, Ltd.

Steel Industry in Brazil

PITTSBURGH, PA.

To the Readers of METAL PROGRESS:

Returning from a stay of eight months in South America, particularly to investigate the metallurgical opportunities resulting from the recent disruption of usual trading arrangements, some general impressions concerning the steel industry in Brazil may be interesting. These observations are given with a background of several years' previous residence in South America as consultant of existing iron, steel and copper producing companies.

Most of my American acquaintances seem to believe that the iron and steel industry is non-existent in Brazil. As a matter of fact, during the past few years it has developed at an accelerated pace and its progress is well worth watching. Brazilian industrialists (under the urgency of the government which, by the way, is a true dictatorship after the European model) show a strong determination to build up a self-sufficient economy. They are proceeding in an orderly manner, they believe, so as to benefit the people generally.

Brazil has enormous mineral resources of all kinds. The exploitation of these may well change the balance of industrial production in the world. In the State of Minas Geraes alone (whose very name indicates "many mines"), iron ore deposits of good quality are estimated to contain over 15 billion tons. The essential manganese is also readily procurable in metallurgical grade.

Numerous small smelters of 10 to 15 tons daily capacity in pig iron, in many points similar to the first furnaces used in Pennsylvania, have been built. During the last ten years, European engineers, mostly from Belgium, France and Luxembourg, have created well-designed and integrated production units with efficient charcoal blast furnaces of capacity to supply substantial and modern rolling mills. The iron ore used contains between 62 to 66% iron and is low in phosphorus. The charcoal is of good quality. Exploitation of the forests is done in such a scientific way that practically an indefinite supply of charcoal is assured. The smelting, steel making and rolling are on a level with the same industry in Sweden and the quality of the products made by some of the Brazilian companies is comparable to Swedish iron and steel products.

The present production in Brazil, while still small, is growing very fast. Available statistics show during the year 1939 a total of 144,000 metric tons of steel shapes produced there against a total of 268,000 tons of imported steel products. However, this gap is quickly disappearing as most Brazilian companies are increasing their capacity.

This can be clearly seen from the figures published by the largest of these companies, namely the Companhia Siderurgica Belgo Mineira. Production from this company's Sabara and Joao Monlevade plants is, in metric tons:

	1939	1940
Pig iron	72,452	84,658
Steel	58,961	85,533
Rolled steel	40,787	74,502

indicating an increase in tonnage of approximately 50% in a year.

This company is adding four more blast furnaces, which when completed will give a total of eight. It is also adding two more openhearth furnaces, which when completed will make available seven excellent 40-ton furnaces. It results, therefore, that by the beginning of next year, the steel production of this company will be well above 150,000 tons per year.

Supplementing the efforts of private Brazilian companies to increase steel production, the Brazilian Government, under the energetic urging of President GETULIO VARGAS, has organized a Brazilian National Steel Co. The design and construction of a steel plant for this company is in charge of the well known engineering firm of ARTHUR G. MCKEE & Co. of Cleveland, Ohio. The new plant *(Continued on page 326)*

The performance capacity of many cast iron parts is greatly improved by flame hardening. The problem is to find the proper irons.

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MOLY

Brazil

(Continued from page 324)

will be located on the South Atlantic shore at Volta Redonda, approximately midway between Rio de Janeiro and Sao Paulo. The iron ore will be shipped by rail from the State of Minas Geraes and coal from Southern Brazil (or coke will be brought in by freighters). The announced capacity will be 300,000 tons of steel products per year.

This project, which our Government is helping to finance, is interesting for several reasons. One of its problems is the production of good metallurgical coke from Brazilian coal. This is needed to permit the use of the rich compact hematite deposits so abundant in Brazil, but which cannot be used alone in the existing charcoal blast furnaces.

When the production of this new mill becomes available, Brazil will be practically independent of importation of many classes of steel products, as estimated by past needs. This increased production, however, will undoubtedly be an incentive to the further development and industrialization of the country. For years to come, the requirements in iron and steel products for its transportation system (railroads, bridges, etc.), as well as for city construction and improvements and for the packing industry, will necessitate a continuous increase in steel production by the existing plants. If to this are added the requirements for building a merchant marine and an adequate Navy, as well as requirements for armament and munitions, the capacity of the existing and projected plants will have to be doubled many times.

As a result of the present lack of available coal or oil near the iron ore deposits, the progressive engineers pioneering the iron and steel industry in Brazil have developed, conjointly with me, several new methods of production of great technical interest. One is a method of rapid refining of pig iron into steel, akin to the process described by Professor PORTEVIN in two of his letters from France. The principle is the same — that is, get an intimate contact between reactive slag and the pig iron — but in my process the pig iron from a blast furnace is partially refined by spreading it out in a thin continuous film in intimate contact with a film of molten slag, separately melted from iron ore and limestone. This removes much of the phosphorus, silicon and manganese and some of the carbon. This metal is then charged, still liquid, in the open-hearth, and requires less than half the usual time to finish.

J. M. MERLE
Metallurgical Engineer

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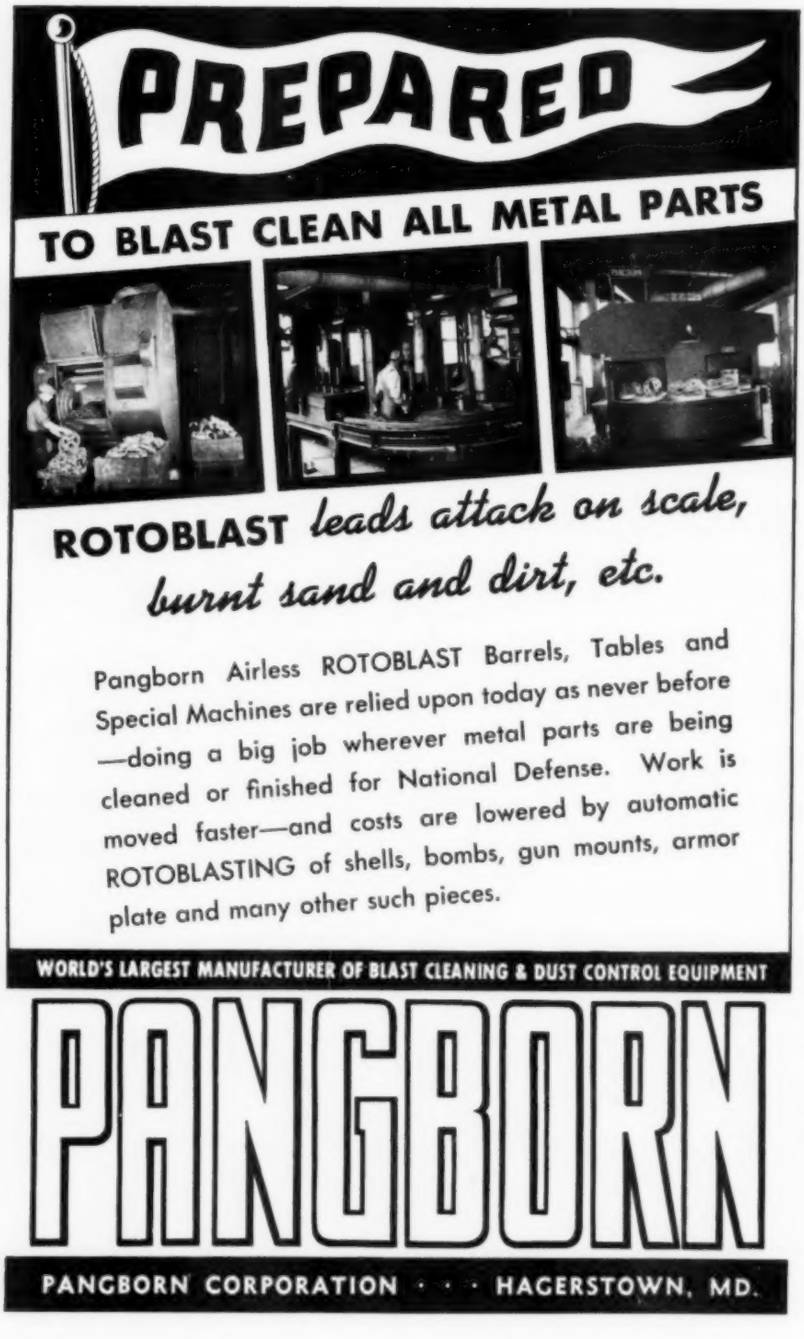
Personals

James T. Kemp, formerly with American Brass Co. in Waterbury, Conn., is now in Washington as adviser on nonferrous metals, Government Conservation Branch, Purchases Division, OPM.

Justus M. Krappe, formerly gas engineering associate at Purdue University, has joined the editorial staff of Western Business Papers, Inc., as technical adviser to *Gas, Butane-Propane News*, and as editor of the Handbook of Butane-Propane Gases.

Eugene E. Everett, formerly metallurgist for Muncie Gear Works, is now with the A. F. Holden Co. in New Haven, Conn.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Paul A. Beck, formerly at the Central Research Laboratory of the American Smelting & Refining Co., has accepted a position as metallurgist with the Beryllium Corp. in Reading, Pa.

Erich Fetz has joined the staff of C. O. Jelliff Mfg. Corp., Southport, Conn., as chief metallurgist.

Norman P. Goss, formerly director of research, Cold Metal Process Co., Youngstown, Ohio, is now research engineer, American Steel & Wire Co., Cleveland.

A. B. Greninger has resigned as assistant professor of metallurgy at Harvard University and is now in the lamp department of General Electric Co., Cleveland.

R. P. Hobson, formerly in charge of the heat treating department, Halcomb Division of Crucible Steel Co. of America, is now superintendent of the bar finishing department, Universal-Cyclops Steel Co., Bridgeville, Pa.

R. P. Schweyer is now with American Car and Foundry Co. in Berwick, Pa.

Transferred: **Robert M. Reynolds**, from Naval Reserve Aviation Base, Atlanta, Ga., as executive officer to maintenance progress, Bureau of Aeronautics, Washington, D. C.

Peter Payson, chief research metallurgist at the Eastern Research Laboratories of the Crucible Steel Co. of America, Harrison, N. J., has been appointed lecturer at the Evening Graduate School of Stevens Institute of Technology.

Appointed as development engineer, Malleable Founders' Society, Cleveland: **J. Arthur Durr**, formerly supervisor of research and metallurgical control at the plants of the Eastern Malleable Iron Co.

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Parts made from all stainless steels can be processed, increasing the life of the wearing parts many times, without any change by SUPER SCOTTSONIZING. The parts remaining non-magnetic and non-corrosive. If the steel used requires a treatment, this should be done previous to our processing.

S.A.E. steels fully heat treated ground to size can be SUPER SCOTTSONIZED, made so hard that no file can even scratch the surface; with slightly increased physical qualities.

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This treatment is new; has no equal. SUPER SCOTTSONIZING is the greatest development made in precision hardening of this decade.

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The first commercial steel treating plant established in the United States.

Personals

Carl H. Samans has resigned as associate professor of metallurgy in the School of Mineral Industries of Pennsylvania State College to become research metallurgist for the American Optical Co. in Southbridge, Mass.

Lt. W. W. Culbertson has been granted a leave of absence from Case School of Applied Science and is in active duty in the Ordnance Department, stationed in the research department of Frankford Arsenal as assistant to the officer in charge of research.

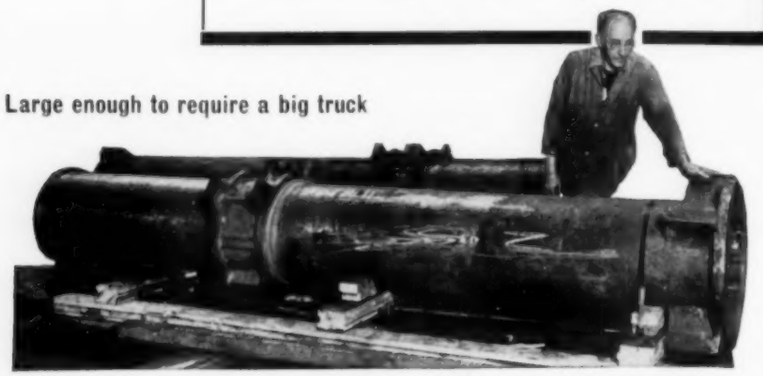
Richard A. Wilde has left Linde Air Products Co. to become a research engineer at Battelle Memorial Institute.

DURALOY

Sound

CHROME-IRON
CHROME-NICKEL

castings of any size



Large enough to require a big truck

Rolls small enough to carry in one's pocket

The word "sound" suggests the skill and experience of our metallurgists and foundrymen.

The words "castings of any size" suggests the completeness as well as flexibility of our modern foundry.

Such foundry skill and such casting service should be of inestimable value to you if you need castings to combat high temperatures, corrosion or abrasion.

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9-DU-2

W. E. Bruse has resigned as metallurgist for the Bendix Aviation Corp., South Bend, Ind., and is now metallurgical engineer, Bureau of Aeronautics, Navy Department, Washington.

George E. Pellissier, Jr., formerly associated with the department of metallurgy, Carnegie Institute of Technology as the International Nickel Co. fellow in metallurgy, is now employed at Stevens Institute of Technology, Hoboken, N. J., in the department of powder metallurgy, on an industrial fellowship sponsored by the same company.

Robert F. Hull, formerly employed as an experimental engineer for Brown & Sharpe Mfg. Co., has accepted a position as sales engineer for Federal Products Corp.

Alfred Boyles, previously metallurgist at Battelle Memorial Institute, is now in the research department of U. S. Pipe & Foundry Co., Burlington, N. J.

Warren H. Mayo has left Columbia University where he held the William Campbell research fellowship in metallurgy and is now employed as metallurgist at the Homestead Plant of Carnegie-Illinois Steel in the ordnance materials department.

William T. Sweeney, who was research associate for the American Dental Association at the National Bureau of Standards, Washington, D. C., has accepted a position as director of research for Vernon-Benshoff Co., Pittsburgh, working on plastics.

Otto Thomas Pfefferkorn, previously employed as metallurgist with Triplett & Barton, Inc., Burbank, Calif., is now a research metallurgist for Climax Molybdenum Co. of Michigan at Detroit.

Elected president of The Edward Valve and Mfg. Co., Inc.: **William F. Crawford**, vice-president since 1937.

keeping you awake nights?

Here's a service that may help you answer them...why not use it?

RIGHT now a lot of good men are losing plenty of sleep over problems like these. Every man responsible for production has them. You just can't lock them up in your desk when you leave the office at night. In the wee small hours they camp beside your rumpled pillow and cry for solution.

We don't pretend to have all the answers but we believe we can really help you in this situation. At least it won't do any harm to let us try. For the service we offer costs exactly nothing. And it has worked out in plenty of cases that looked awfully tough at first glance.

What we offer you is the cooperation and advice of our metallurgical contact staff. Men who know steels. A group of well-trained, long experienced shop-wise experts who have specialized in smoothing out production bugs. These men will be glad to come into your plant, look over your blueprints, check up on your facilities, and work with you in making more efficient use of available materials, equipment and personnel. They've been doing similar work for a good many years. Right now with the battle of production reaching new peaks, they are getting results that would have seemed impossible a short time ago. For prompt action, phone or wire the nearest Carnegie-Illinois office.

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CARILLOY *Dependable* ALLOY STEELS

USS

Wear Scruff*

By H. J. Goldschmidt and G. T. Harris

THE MECHANISM of wear has never been fully established, owing to the large number of factors controlling the phenomenon. Thus, the wear resistance of a solid, in contrast to other physical properties, is affected by such factors as surface finish, melting point, and humidity of the surrounding atmosphere, while other factors, such as hardness, which might be expected to exert a strong influence, do not appear to do so.

In the experiments now to be discussed a wear testing machine was used in which a revolving wheel of hardened and tempered high speed toolsteel is forced under constant load against a plane sample to be tested, wearing in it a groove whose length (and volume) is a function of the wear resistance. The tests were run without any lubricant and the fine powder formed by the abrasion was collected and examined by X-ray diffraction.

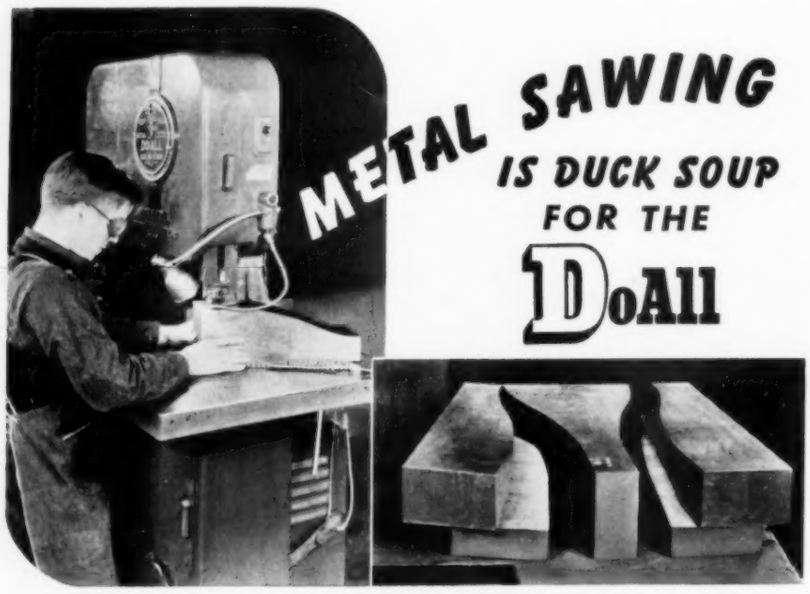
The photographs of the powders as collected showed highly diffuse diffraction lines, indicating a very small particle size (less than 10^{-5} cm.), or severe internal strains. There is no evidence so far to discriminate between these characteristics and probably both are present. In view of this, the powders were stress relieved by annealing in vacuo at moderate temperatures, when sharp lines were obtained.

From data obtained on a range of carbon steel samples, the essential conclusions may be stated as follows: (1) The wear powder consists of iron oxides and some of the parent metal (alpha ferrite). (2) The observed oxides are magnetite, Fe_3O_4 (spinel structure), and woostite, FeO (sodium chloride type of structure). (3) The relative amounts of Fe, FeO and Fe_3O_4 depend characteristically on the composition and constitution of the steel and on other relevant factors such as pressure. (4) Hematite, Fe_2O_3, the oxide richest in oxygen, is never found. (5) Cementite, Fe_3C, occurs in some of the wear powders from the higher carbon steels and its presence is accompanied by an increase in FeO content. (6) The heating and cooling effect of wear can be considered as equivalent to a kind of localized heat treatment, both on the powder and on the material.

As an example of the type of phenomena observed, the results obtained on a series of plain carbon steels may be considered. The series ranged from spectro-

(Continued on page 350)

*Abstract of "An X-Ray Examination of Mechanical Wear Products", *Journal of Scientific Instruments*, May 1941, p. 94.



On the DoAll, the Hawthorne Metal Products Co., Detroit, Mich., cut the five sections of a die from one block of boiler plate steel 5" thick, 16" long, 14" wide—only 4 cuts of the saw necessary. Time—1¾ hours for each cut, or at the rate of ¼" per minute. Saw used—½" 6 R.H. Speed—150 f.p.m.

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Specifying Standard Corrosion-Resisting Alloys

Many manufacturers of alloy castings have adopted the following designations for standard Corrosion-Resisting Alloys:

CA-14, containing 11.00% to 14.00% Chromium, 1.00% maximum Nickel, .14% maximum Carbon. This is one of the straight Chromium analyses used primarily for mild corrosive service.

CF-7, this is one of the 18.00% Chromium, 8.00% Nickel combinations, with a maximum Carbon content of .07%, and is adapted to a great variety of uses in chemical plants and for die house and paper mill machinery.

CF-7-M, this is a modification of the above 18.00% Chromium, 8.00% Nickel analysis, also containing .07 maximum Carbon, but fortified by 2.00% to 3.50% Molybdenum. Molybdenum is a strength inhibitor against intergranual corrosion.

CF-20, it is generally conceded that this is most universally used of the 18.00% Chromium, 8.00% Nickel Alloys. This combination is produced with a maximum Carbon content of .20%. Its uses are very numerous and most engineers are familiar with this type material.

CH-20, this analysis is usually known in the trade as one containing approximately 25.00% Chromium, 11.00% Nickel, with a maximum Carbon content of .20%. This Alloy is very extensively used for both Corrosion-Resisting and Heat-Resisting services, and is a very popular one with the paper and pulp industry.

CE-30 this analysis is generally known as one containing 28.00% Chromium, 10.00% Nickel, with a .30% maximum Carbon. This Alloy has very excellent Corrosion-Resisting properties and is used to a great extent in the paper, pulp and mining industries. It is also resistant to high temperatures, and particularly serviceable where high temperatures are combined with sulphurous temperatures.

Fields in Which **STEEL CASTINGS** Are Constantly Used

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Agricultural Machinery
Automotive
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Boiler, Tank & Piping
Bridge
Chemical & Paint Works
Compressors (Pneumatic)
Conveyor & Material Handling
Crushing Machinery & Cement Mill
Dredge
Electrical Machinery & Equipment
Elevator
Engine
Food Processing & Packing Plant
Foundry Machinery & Equipment
Gas Producer & Coke Oven
Gears
Heat Treating Furnace & Equipment
Hoist & Derrick
Iron & Steel Industries
Metallurgical Machinery
Mining Machinery & Equipment
Oil or Gas Field & Refinery
Ordnance
Overhead Crane & Charging Machine
Paper Mill
Printing Press
Pump
Railroad
Refractory, Brickyard & Ceramic
Refrigeration Machinery
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Unitcast Corporation, Steel Casting Division
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Philadelphia, Pa.
Dodge Steel Company
MAYfair 1650

Rochester, New York
The Symington-Gould Corporation
Genesee 101

Tulsa, Oklahoma
Oklahoma Steel Castings Company
1200 N. Peoria. 5-9286

Wear Scruff

(Continued from page 342)

scopically pure iron to a steel containing 1.03% C. The volume of the impression (an inverse measure of wear resistance) of the annealed samples was 9 for the iron, rising to a maximum of 21 for 0.45% C steel, thence through a minimum of 9 for 0.8% C steel and rising to 19 for annealed 1.03% C steel. The latter, quenched to martensite plus free cementite, had the maximum resistance; its depression measured 1.

The amounts of the constituents present in the scruff did not follow these variations. Ferrite was in large proportion in all. The amount of Fe_3O_4 was a mere trace in the scruff from pure iron and the 1% C steel, but rose to a large amount in steels containing 0.4 to 0.7% carbon. An exactly inverse condition existed with the FeO present. Cementite was present in somewhat variable amounts for a given steel, and this amount increased with the observed FeO contents. It is probable that the hard carbide behaves as a grinding agent resulting in an increase of temperature into the region of stability of FeO (1060° F.). The fact that FeO is present implies that this temperature has been exceeded. The facts that the oxygen supply must be limited by the intimate contact, and that the time allowed for reaction is so small, would both favor the formation of the oxygen-poorest oxide FeO and inhibit the formation of the oxygen-richest oxide Fe_2O_3. This suggests that the wear products have been formed at a high temperature and are in effect subsequently "quenched", which would be the effect on very small particles produced by rapid cooling.

It is indeed likely that local temperatures are produced above the transformation range of the medium carbon steels. It is possible therefore that, in such a range, local hardening may take place due to "quenching" from above the critical temperature. The wear process is thus equivalent to a quench from the austenitic region and a higher carbon steel is more likely to form martensite, which being so hard would act as an abrasive and accelerate wear if any of the particles were caught between the wheel and the work. For hypereutectoid steels there may be carbide particles worn away to give abrasive debris and increase the wear. In a martensitic steel it is possible that due to greater hardness the friction may be less and the temperature lower, with the result that the martensite is "tempered" and wear may be less.

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Excellent Tool Life and Finish.
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To friends both old and new . . . thanks for your patience. We are doing our very best for Defense . . . and also for you.

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Q-ALLOYS THE QUALITY NAMES IN ALLOY FOR HEAT CORROSION ABRASION X-ite

Capt. "Danny" Duggan

AVE known "Wild" Irishmen and ones that get wild on spirits, but, Duggan tops the list. Captain Duggan died flying in an "acci- to a Ferry Service Transport plane ing from England. Twenty other mostly American, who had flown s to Britain, shared his fate. Bos- pers are running a serial on "Dan- life entitled, "Hellion, Heaven .

ANNY was Chief Pilot for Shobe Air- then he flew tri-motors for May- Airlines on the foggiest commercial Boston, Nantucket and New Bed- He made top marks in every job, his extra-curricular activities made 's comet look stagnant. Danny lized in rule breaking. He flagrant- nted all regulations, and greeted fficials with two yards of unpunc- profanity. He made vertical banks the mast heads of incoming fishing His heart and his pocket were to all.

HE English can't win without the " said Danny, who began training an pilots when the war started. ferried some of the first bombers the pond and was doing it weekly. was a PIONEER, a "trade" that es one pair of "ears" per male baby, short on apprentices. Danny car- a St. Christopher's medal and a rab- foot on his key chain. "Some day Rabbit may need help," said he.

WE always wanted to get Tommy Breene and Danny Duggan together. The consequences would have made headlines.

NORMALLY disbelieving in signs we print one that is too potent a comment on National Defense to pass by, "Danger Men Working Slow".

BLACK and white prints from color photographs are unsatisfactory. Some day MP will run in 4 colors, meanwhile active imagination can fill in the colors on the airplane's shadow, cast on a cloud in bright sunlight. The aurora of concentric rings has the colors of the rainbow. Fragile fleeting beauty lens-frozen 4 miles above the sea.

WE have haltingly constructed a fragmentary philosophy on the tenets that Science is the Progenitor of Truth and, "That which is truly functional is truly beautiful." Our lagging thought is fanned to flame by four volumes, from a bombed British Library, and just added to ours, *"Robinson's Mechanical Philosophy," published in Edinburgh in 1822.* (Title page reproduced herewith.) This work includes a chapter by Isaac Watt on the History of the Steam Engine, and has other chapters on machinery, the resistance of fluids, rivers, water works, pumps, dynamics, projectiles, corpuscular forces, strength of materials, carpentry, construction of arches and bridges, astronomy, the telescope, and pneumatics. Electricity, magnetism, temperament of the scale of music, the trumpet, watch work and seamanship.

THE knowledge of mechanical philosophy which these dissertations display possesses the rare quality of being at once practical and profound and they are often enriched with original views and ingenious inventions.

OF electricity, 120 years ago, Robinson writes, "It is by a mathematical view of the subject in the phenomena of attraction and repulsion that the celebrated philosopher Franklin was led to the only knowledge of electricity that deserves the name of science, for we had scarcely any leading facts by which we could class the phenomena until he published the theory of positive and negative or plus and minus electricity." (We suggest a *positive* stand in demanding Q-Alloy and X-ite castings to insure *negative* "grief".)

AS we are swiftly tossed by the surface currents and eddies of modern life, as we currently leap the hectic hurdles of delayed defense with simulated heroics, it is well, for needed relief, to drop an anchor of sanity in the deeper currents of human progress by tapping a good library. We think we are travelling "like a bat out of hell" until we lay our stop watch against the calendar and the calendar against history. And of course we will have reactionaries, example: Plaintiff: "I desire to change my name." The Court: "What is your name?" "Herbert Hoover Stinks," replied the Plaintiff. "You have my sympathy," remarked the court, "and what new name have you chosen?" Plaintiff: "Franklin D. Roosevelt Stinks."

MAY we remark that there will be less "stink" around your heat treat if your solution pots are Q-Alloy and if your gas carburizing muffles and retorts are engineered and manufactured by General Alloys.

THE defense program makes it increasingly difficult to justify supplying castings from low grade producers in industrial furnaces. A few pounds of "low first cost alloy" failing in service may well jam a production line and delay priceless defense effort. Most of the leaders in defense efforts have brought, like General Alloys, the tradition of good name and outstanding achievement to new highs. The preference for General Alloys' engineering and heat resisting castings among this group is even more pronounced than in the general market, where General Alloys has long been recognized as the "ablest, the oldest and the largest manufacturer of heat and corrosion resistant castings."

AT the National Metal Exhibition at Philadelphia, October 20-24, 1941, General Alloys will be, *for the 22nd consecutive year, the largest exhibitor in our line,* and this writer will pass a 42nd birthday with thanks that this organization has the youth and vitality to build a future of service to National Defense and American industry. We have the advantage of unequalled *personnel facilities, technology and experience* in this young dynamic alloy field, and we accept the stern responsibilities of leadership.

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OF
MECHANICAL PHILOSOPHY

ENERAL ALLOYS COMPANY - BOSTON, MASS.

E FOOTSTEPS OF GENERAL ALLOYS MARK THE PATH OF AN INDUSTRY
GA X-ITE GA O'ALLOYS GA X-ITE GA O'ALLOYS

Contributors

On June 28, 1940, the German Army entered Angouleme, near Bordeaux, and later the same day a letter was posted from that place to Metal Progress from Professor **Albert M. Portevin,** for 12 years a steady correspondent concerning matters metallurgical in France. Since that date complete silence.

Thirteen months later another letter arrived, dated June 16, 1941. The envelope contained several short contributions. The envoy also contained this personal news:

"Having been able to come for a few days into the unoccupied zone, I am profiting by the occasion to write to you, for since the invasion I have been living with my family in the occupied zone. Happily we are really all in good health, in spite of the painful events we have passed through and the difficulties of all sorts which we encounter at this time. Best wishes to you and to all my friends in America."

One wonders about the fate of *La Revue de Métallurgie,* of which M. Portevin was editor. No copies have been received since April 1940.

James Presley Gill has grown up with the science of toolsteel metallurgy, having been chief metallurgist for Vanadium-Alloys Steel Co. since the tender age of 24 (some 20 or more years ago). His education was obtained at Missouri School of Mines and Columbia. His numerous services to the ASM were topped by his election to the presidency in 1939. He was chairman of the Pittsburgh Chapter in 1926-27, and presented the Campbell Memorial Lecture in 1936, chairman of the Metals Handbook Committee in 1939, and is the author of "Tool Steels" published by the ASM.

Dartmouth College, University of Pittsburgh and the graduate school of Carnegie Institute of Technology were attended consecutively by **Robert S. Rose,** co-author with Mr. Gill of the article on page 283 on High Speed Steel, before he entered the metallurgical laboratories of the Vanadium-Alloys Steel Co. He was transferred in 1932 to Springfield, Mass., where his title is sales metallurgist for the New England district. He was chairman of the Springfield Chapter ASM in 1934-35.

Orlo E. Brown, who describes the equipment for electrolytic polishing on page 298, is assistant professor of chemical engineering in charge of metallurgy at West Virginia University. Following graduation in 1928 from the University of Wisconsin he was on the technical staff of Simmons Co., later going to A. O. Smith Corp. After returning to his alma mater for chemical engineering and metallurgical engineering degrees, he worked for a supervisory division of the Treasury Department. He left this to go with Globe-Union, Inc., which preceded his entry into academic work.

C. N. Jimison, co-author with Professor Brown, graduated in chemical engineering with a metallurgy option from West Virginia University in 1940. At present he is completing the requirements for a Master's degree, doing graduate research work in metallurgy. He is also an instructor in metallurgy under the U. S. Engineering Defense Training program.

The reports starting on page 307 were prepared at the request of the Office of Production Management in the record time of two months. Credit for this work goes to the personnel of the three committees. **Norman I. Stotz,** who is metallurgical engineer for Universal-Cyclops Steels Corp., acted as chairman of the committee on heat treatment of molybdenum high speed steels; **A. F. Holden,** president of the A. F. Holden Co., manufacturers of heat treating salts, is chairman of the committee on the salt bath method for hardening; and **C. I. Hayes,** president, C. I. Hayes, Inc., well-known furnace manufacturers, heads the committee on controlled atmosphere furnaces. **J. Edward Donnellan,** editor of the ASM Metals Handbook, secretary of the Metals Handbook Committee, and of all the technical subcommittees that collaborate in its preparation, was an apt choice for secretary of all three.

Robert S. Rose

Albert M. Portevin

C. N. Jimison

Orlo E. Brown

James P. Gill

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THE greatest metal event in years—the forthcoming National Metal Congress and Exposition—will be featured in the October issue of Metal Progress. This is the monthly magazine of the American Society for Metals, sponsor of the Exposition.

This Metal Exposition Pre-View will be in the hands of more than 13,000 A.S.M. metal men before they leave for the Show, and will be circulated at the Show itself as an accepted feature of this event.

But this Pre-View is only one of the features of Metal Progress in October. Complete editorial and advertising sections, each with its individual front cover, will feature these eight topics—

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•
Heat Treating and Finishing
•
Testing and Control Instruments
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Steels and Irons
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Weldability of Non-Ferrous Metals

By E. G. West

Abstracted from *The Metal Industry*, Dec. 29, 1939, p. 553.

THE CAPACITY for satisfactory weldability depends upon the welding process and the purpose of the weld, as well as the relevant properties of the metal to be welded. In gas welding the oxy-acetylene flame is generally used for metals and alloys of high melting point. The temperature attained, over 6000° F., gives a narrower heated zone than welds made with other gas flames, and enables higher working speeds. Other gas fuels possess many desirable characteristics for non-ferrous metals other than copper or nickel, but butane and propane are not yet used in any appreciable quantities in Great Britain.

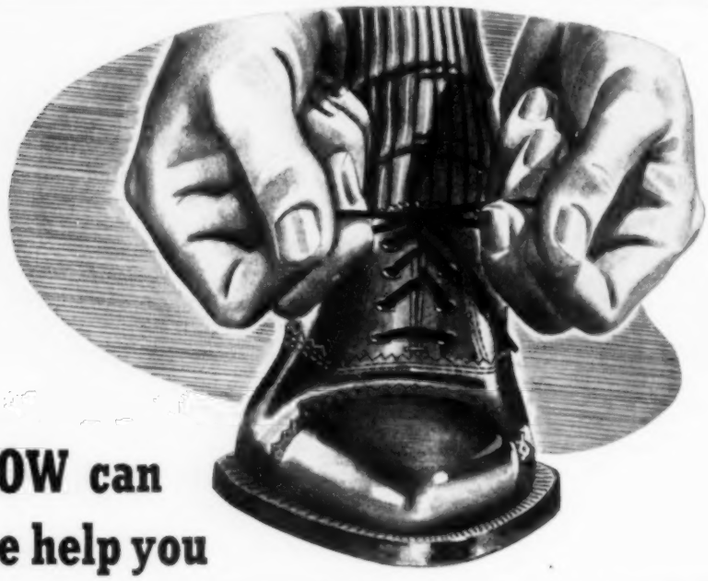
The non-ferrous metals are usually extremely sensitive to small changes in the atmosphere at elevated temperatures, either when solid or liquid, but it is seldom that one sees a welder using accurately controlled blowpipe equipment and flame adjustment in a continuous operation. The merits of the "right-hand" and "left-hand" method for some of the alloys should be investigated.

In arc welding, direct current is now preferred for non-ferrous metals, but the possibilities of using alternating current of higher than normal frequencies require exploration. The most important future developments lie in electrode coatings. The sleeve electrode (as developed for copper by Lessel) appears to be most promising.

The atomic hydrogen method works at an extremely high rate, and produces a narrower annealed zone, but the equipment's shape and size militates against its wider adoption. However, slag-free joints are obtainable and it is worthy of consideration for thin sheets.

The properties of most non-ferrous metals increase the difficulties of resistance welding and render comparisons with mild steel of little value. The influence of the resistance between surfaces in contact is but poorly appreciated, although it is of particular importance in aluminum alloys. The high currents frequently required, coupled with the extreme accuracy of control, have stimulated the production of precision machines and timing gear. Copper-cadmium alloys have proved to be satisfactory electrode materials

(Continued on page 360)



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- ☐ 124-page "Handbook of Special Steels," containing a valuable Stainless Selector Chart.
- ☐ Certified Technical Data on individual Stainless Steel Grades (Blue Sheets).
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62

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A. FINKL & SONS CO.

. . since 1879 CHICAGO

Weldability

(Continued from page 358)

but conditions now being encountered demand copper containing such additions as tungsten or chromium. Designers, welding engineers and operators must be specially trained.

It is convenient to consider the suitability of a weld under three headings:

Mechanical Effects — The total amount of shrinkage is a function of the metals concerned, while its effects depend on a number of factors peculiar to a particular application. In general, the non-ferrous metals expand much more than the steels, and failure to appreciate this is a prolific source of disappointment.

The *metallurgical conditions* which are likely to influence the useful life of a weld are *(a)* differences in composition and structure between the weld and the parent metal, *(b)* alteration in structure of the parent metal due to the welding operation. The production of molten metal is the basis of fusion welding and the desired result is a "sound casting", so that the processes and precautions resemble, essentially, those of the foundry. The molten metal is purified by elements added to the filler rod and by the flux.

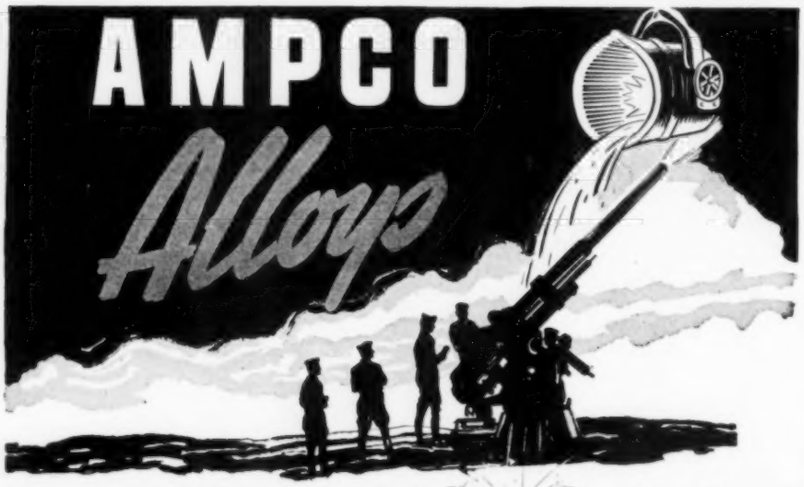
When the structure of the weld metal is too coarse it is sometimes possible to incorporate elements in the basic metal, filler rod or flux which will reduce the difference in grain size between weld and metal.

The speed of welding, the amount of flux used, and the idiosyncrasies of a particular operator may alter the degree to which the reactions proceed, while the presence of small quantities of impurities (including gases) may introduce differences in the welding behavior of materials, apparently similar and complying with the same specification.

The distribution of the constituents of the base metal in the heat affected zone may be completely altered, thus altering the mechanical and other properties, such as corrosion resistance.

Available Tests — There is no single test which gives adequate information as to either the general weldability of a material or the efficiency of a joint for service. The sectioning of a weld, followed by a microscopic examination, provides more information than any other one test.

Thus, certain properties of the metal or alloy are of chief importance in the choice of the process and technique to be used; others influence the method of setting up, the necessity for preheating, and the cooling procedure.



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Government contractors in ever-increasing numbers are relying on AMPCO for metals of the aluminum bronze class, and other copper base alloys that meet Federal, Army, Air Corps and Association specifications. *Write for details of our facilities to supply better bronze alloys.*

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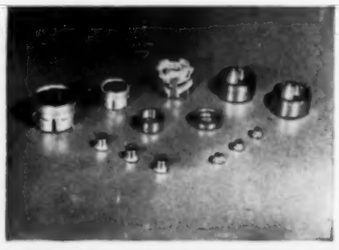

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SYRACUSE, N. Y.	*Welding Supply Co.*
TOLEDO, OHIO	*Williams & Co., Inc.*

British Steel

(Continued from page 288)

supplies. This has entailed great adaptations at works and led to difficulties which have called for the greatest ingenuity.

At the same time, from the outbreak of war up to the present time considerable quantities of finished and semi-finished steel have been imported, the opportunity being taken when the shipping position was still comparatively favorable to build up large reserves in Great Britain. Mild steel imports have now been substantially reduced. The imports of high-grade raw material supplies necessary in the production of special steels are being maintained at the highest possible level.

(3) *Q.* — Are there any difficulties experienced regarding transport?

A. — So far as imports from abroad are concerned, during the winter months there were difficulties consequent upon congestion at the ports due to the very large quantities of material arriving, the restrictions in order to comply with black-out requirements and bombing raids. This had its reaction on home-produced supplies, through shortage of transport vehicles, both rail and road.

(4) *Q.* — What is the effect on production of alerts and black-out conditions?

A. — This, naturally, varies in different districts; but, thanks to the Observer Corps warning system, there has, broadly speaking, been little loss. It should be borne in mind that the steel industry differs from practically any other in respect of the immense glare and amount of light thrown off during operations. Consequently, the necessity of achieving a good blackout has entailed some loss of ventilation. The men have stood up remarkably well to the trying conditions under which they work.

(6) While doing everything possible to maintain production, various methods have been studied by the Iron and Steel Control to effect economy in the use of steel. This research has led to the use of material lighter than that normally specified and considerable economies have been achieved, amounting, in some cases, to many thousands of tons per annum. Two typical examples are the reduction in the weight of tubes for gas, water and steam purposes and insistence on the use of light-weight tubes wherever pressures are suitable, and an order restricting the use of tin-plate containers, which specifies the gage of material to be used. The first will save 20,000 tons of steel and the second 35,000 tons of tin plate per annum.

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Much work in this shop must meet rigid government inspection. All Gleason, Fellows Gear Shapers, Lee Bradner and Brown & Sharpe machines, are operated with Cities Service Lubricants. You, too, will find these high-quality fluids capable of doing the kind of work your customers want.

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By giving steel data in terms of actual physicals, the Machinery Steel Selector enables you to pick the right steel in any size up to 8" without guesswork. Use your Selector—for another one, write the nearest point listed below.

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TAM Foundry Zirconite Sands in two grades, "A" and "B" (differing chiefly in melting points) are fine grain core and mold sands ready for use by the foundry. They possess high resistance to "burn in" and yield castings which clean rapidly and require but little subsequent work in the chipping and cleaning department.

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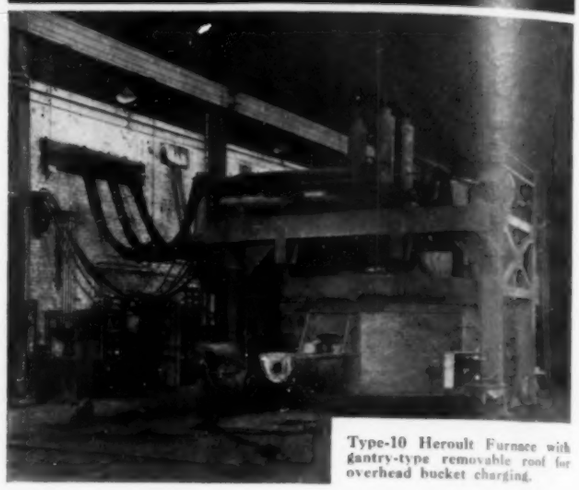

Type-10 Heroult Furnace with gantry-type removable roof for overhead bucket charging.

USE them for efficient melting and refining of all kinds of ferrous materials by either basic or acid process—including alloy, tool and forging steels, iron and steel castings. Any capacity from ½ ton to 100 tons; removable roof, chute, machine or hand charging.

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In many annealing and heat treating processes, dry controlled atmospheres are advantageous. When thorough, dependable, and economical dryness in controlled atmospheres is desired, investigate LECTRODRYER. The LECTRODRYER — Activated Alumina System—provides bone dry atmospheres continuously.

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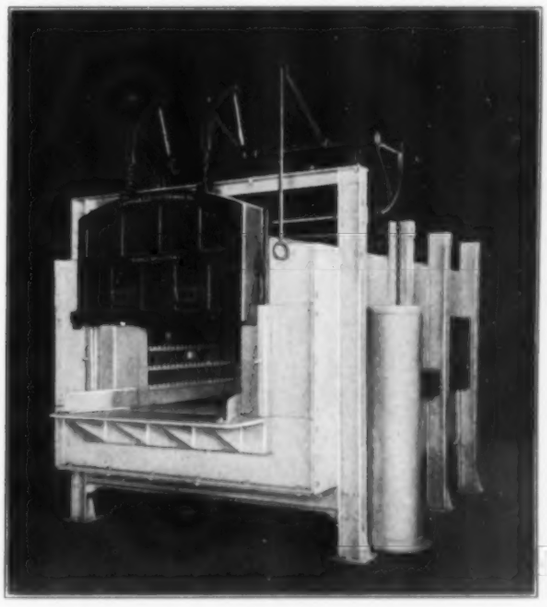

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Hearth 36" wide by 84" deep

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The rigid government specifications are readily met when "AMERICAN" Electric Furnaces are used. Uniformity is increased, rejections decreased and production interruptions eliminated.

Profit from the experience gained in decades of ordnance and small arms manufacture by installing furnace equipment that has a record of success.

Write for bulletins today!

AEF

American Electric Furnace Company

30 VON HILLERN ST. ★ BOSTON, MASS., U. S. A.

Industrial Furnaces for All Purposes

Fabrication

(Continued from page 292)

alloy steels don't vary widely in machinability rating; they all have excellent toughness (a condition opposed to machinability) and in the annealed condition their hardness is usually not far from 180 Brinell.

Cold drawing will help the soft, low carbon materials, for it will bring up the hardness.

At high hardness, here are some figures that I offer based simply on my own experience. S.A.E. 1050 at 280 Brinell will machine about as fast and with as good tool life as 3150 at about 341 Brinell; 4150 at about 375 Brinell; X-4340 at, say, 418 Brinell. Of course, none of those materials at those hardnesses is "machinable" in the sense that screw stock is. However, they can be machined commercially. Those figures have no degree of finality; X-4340 is in some plants being machined at Brinells around 500. Tool life, of course, is unsatisfactory, the rate of metal removal is low, but the economics of heat treating first and then machining may work out much more satisfactorily that way.

Machinability Ratings (G.T.W.)

Cold Drawn	
S.A.E.	Value
1112	100
X-1112	135
X-1315	85
X-1335	70
X-1020	75
1020	65
1040	60
3115	50
4615	60
2515	30

Annealed	
S.A.E.	Value
3140	55
4130	65
4150	45
5140	45
4640	55
6140	40
1330	50
1340	40
2350	35
52100	30

The majority of machinability problems are non-metallurgical — caused by some shop factor. First is the rigidity of the equipment; recently I heard of a job that "could not be machined"; finally the shop was persuaded to put a steady-rest on the job to get rid of chatter and then there was no more trouble. Control of both speed and feed is vital if best machining is to be gotten. The lubricant will have an important effect, whether it really has lubricating qualities or whether it has cooling qualities, or both, and the amount in which it is supplied. The old custom of letting a little soluble oil emulsion trickle over the point of the tool was bad. Likewise, those fellows who have

(Continued on page 382)

Molybdenum NO Problem
for
SENTRY *Packaged Atmosphere*

Molybdenum steel hardening requires an absolutely *neutral* atmosphere. For ten years Sentry Furnaces and the Sentry Diamond Block Method have turned out high quality Molybdenum hardening without scale, decarburization or soft surface. It is no problem to Sentry.

Let us tell you how it will be no problem to you—how, without fuss or adjustment you can obtain quality hardening of Molybdenum and all other high speed steels consistently and with economy.

Sentry High Speed Steel Furnaces are available in floor, bench or pit types. Illustrated is a Size No. 3, Model "Y" Electric Furnace. Write for complete information. Bulletin 1022-A.

Sentry Diamond Blocks automatically maintain a *neutral atmosphere.* Available in sizes to meet requirements.

Sentry "Always on Duty"

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The Care and Feeding of... an IDEA

Powder metallurgy, in certain well-established applications, is far from a fledgling. But current explorations of the possibilities of powders and the uses of sintered powdered metal parts, are producing new ideas that deserve nourishment.

Potentially, powder metallurgy offers important economies and saving of time in the production of a vast number of parts used in industry. Its specific application to making a given machine part (or material for fabrication into a part) may today be just an idea. To foster the idea into practical realization is the respon sibility of metallurgist, machine designer and *manufacturer of metal powders.* It is essential to design with the limitations as well as the possibilities of metal powder manufacture in mind. Powders must be manufactured to definite specifications based upon desired properties for the particular application.

We have been producing metal powders of all types for a quarter of a century. We have learned a good deal about what can be done with this special production technique. The experience of a considerable staff of metallurgists, chemists and engineers is at the disposal of manufacturers. We welcome requests for information.

METALS DISINTEGRATING COMPANY

ELIZABETH NEW JERSEY

PIONEERS IN METAL POWDERS FOR A QUARTER CENTURY

September, 1941; Page 381

Fabrication

(Starts on page 289)

learned that a trickle is not enough may still get in trouble by having a large supply, but having it come down so the tool keeps the stream of lubricant from getting in where it has to work. Finally, the form of the tool is most important — a good machinist can do wonders by touching up the shape of the tool to meet the requirements.

From the strictly metallurgical standpoint, the material in process must be homogeneous, developing strength uniformly, and it must be kept so. If a shop-man today has a piece of 1045 that machines with a given set-up at a satisfactory rate, and tomorrow he gets in a new batch of material and he can no longer make out, the trouble may be due to the non-homogeneity of the steel or variation in its heat treatment in process.

Grinding — As far as grinding is concerned, there is again not much we can do about it; we must select our material for other things and put our confidence in the grinder. The grinder can do a great deal toward eliminating some troubles following his work if he is careful. If he will keep the grinding wheel clean and free of glazing, he will go a long way toward eliminating cracks, and this applies particularly to carburized work. Grinding means local overheating, and the use of a coolant is very desirable; seeing that the coolant gets where it belongs is more important. Also the choice of the wheel to be used is a very important factor; for the sake of wheel life, we want to use as hard a wheel as possible — but that is the fastest way to crack material there is.

Keep grinding wheels in good condition; use soft wheels and feeds that are relatively small.

I recall one plant where carburized parts were gradually replacing intermediate carbon steel. In every department where casehardened work was put for the first time, complaint arose that something was wrong because the parts were cracking on grinding. That was a job where laziness had an application. By sitting back and telling them I was doing everything possible, they got out of the trouble by themselves. There was no metallurgical solution to their troubles, because the case was free of network carbides and the parts were properly tempered.

A final remark may be to the effect that there are a great many "metallurgical" problems that are not problems but are just shop notions. By the same token, some troubles are serious that we don't recognize as such in their early stages.

I'D RATHER BE RIGHT THAN BE LEFT

ALTER EGO: Literally, "one's other self"—the still, small voice that questions, inspires, and corrects our conscious action.

Sure there's going to be some scrambling when we get back on a 40-hour week. It will be time enough then *to consider whether we'd be right in changing to arc welding.*

ALTER EGO: There won't be time enough then to even consider what hit us.

You mean it will take us a long time to get into welding production?

ALTER EGO: I mean it has taken us far too long already to get into welding *prediction.* Prediction as to what will happen to designs and production methods now that all our friends are going great guns with welding for land, sea and air equipment.

There's no doubt about it, they're getting well up in the welding art.

ALTER EGO: Yes, they're learning the knack in the nick of time. And if we don't have the foresight to get into this *right* away — we'll be *left,* holding the bag . . . on which the closure is foreclosure.

• •

LINCOLN SUGGESTS: The *quickest, surest* way to get things accomplished with welding is: Appoint a man of experience and authority to supervise changeover of one part at a time. If this is done, the problem of how to get going will solve itself. We *guarantee* this plan to be profitable. For details, see Page 1, "How to Change Over to Welded Design for Profits".

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Largest Manufacturers of Arc Welding Equipment in the World

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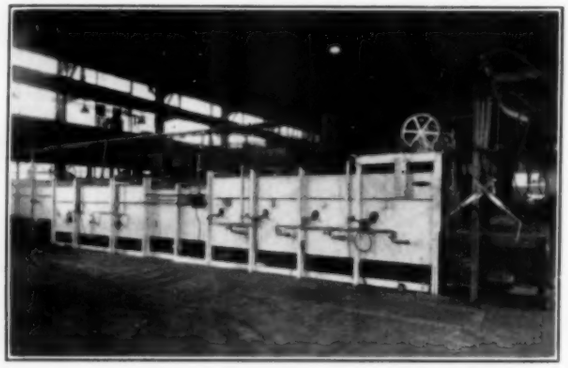
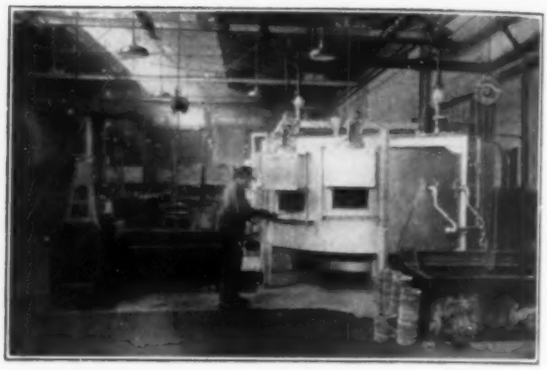
Car Type Furnace

Conveyor Type Furnace



Pusher Type Furnace



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LOCATION OF CONVENTION AND EXPOSITION

1920 — PHILADELPHIA	1925 — CLEVELAND	1931 — BOSTON	1937 — ATLANTIC CITY
1921 — INDIANAPOLIS	1926 — CHICAGO	1932 — BUFFALO	1938 — DETROIT
1922 — DETROIT	1927 — DETROIT	1933 — DETROIT	1939 — CHICAGO
1923 — PITTSBURGH	1928 — PHILADELPHIA	1934 — NEW YORK	1940 — CLEVELAND
1924 — BOSTON	1929 — CLEVELAND	1935 — CHICAGO	1941 — PHILADELPHIA
	1930 — CHICAGO	1936 — CLEVELAND	

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† Deceased

CONSOLIDATED PROGRAM

National Metal Congress

AMERICAN SOCIETY FOR METALS — AMERICAN WELDING SOCIETY
AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS
THE WIRE ASSOCIATION

Sunday, Oct. 19, 1941

5:00 P.M. American Welding Society (A.W.S.) President's Reception; Bellevue-Stratford Hotel

Monday, Oct. 20, 1941

9:00 A.M. ⊜ Alloy Steels Session; Benjamin Franklin Hotel
9:00 A.M. ⊜ Fabrication Session; Benjamin Franklin Hotel
9:00 A.M. ⊜ Research Methods Session; Benjamin Franklin Hotel
9:30 A.M. A.W.S. Presentation of Medals and Prizes; Bellevue-Stratford Hotel
10:00 A.M. American Institute of Mining and Metallurgical Engineers (A.I.M.E.) (Institute of Metals Division) Session on Copper and Tin Alloys; Ritz-Carlton Hotel
10:15 A.M. A.W.S. Session on Weldability of Plain Carbon and Low Alloy Steels; Bellevue-Stratford Hotel
10:30 A.M. A.I.M.E. (Iron and Steel Division) Session on Physical Chemistry of Steel Making; Ritz-Carlton Hotel
11:30 A.M. ⊜ Defense Meeting; Benjamin Franklin Hotel
12:00 M. National Metal Exposition opens; Convention Hall
12:15 P.M. A.I.M.E. Committee on Physical Chemistry of Steel Making, Luncheon Meeting; Ritz-Carlton Hotel
2:00 P.M. A.I.M.E. (Institute of Metals and Iron and Steel Divisions) Joint Session on Physical Metallurgy; Ritz-Carlton Hotel
2:00 P.M. A.W.S. Non-Ferrous Research Session; Bellevue-Stratford Hotel
2:00 P.M. A.W.S. Shipbuilding Session; Bellevue-Stratford Hotel
2:00 P.M. A.W.S. Training Session; Bellevue-Stratford Hotel
2:30 P.M. ⊜ National Defense Group Meeting on Low Carbon Alloy Steels (Casehardening Steels); Convention Hall
2:30 P.M. Wire Association (W.A.) Opening Session; Hotel Philadelphian
5:00 P.M. ⊜ Lecture Course, Heat Flow in Metals; Convention Hall
7:30 P.M. A.W.S. Industrial Research Conference; Bellevue-Stratford Hotel
8:00 P.M. ⊜ National Defense Group Meeting on Manufacture of Shells; Convention Hall
8:00 P.M. ⊜ National Defense Group Meeting on Fabrication of Aluminum and Magnesium Alloys for Defense Material; Convention Hall
8:00 P.M. ⊜ Lecture Course, Hardness and Hardness Measurements; Convention Hall
9:00 P.M. A.W.S. Educational Conference; Bellevue-Stratford Hotel
10:30 P.M. National Metal Exposition closes

Tuesday, Oct. 21, 1941

9:00 A.M. ⊜ Hardenability and Physical Properties Session; Benjamin Franklin Hotel
9:00 A.M. ⊜ Corrosion and Stainless Steels Session; Benjamin Franklin Hotel
9:00 A.M. ⊜ Session on Heat Treatment; Benjamin Franklin Hotel
9:30 A.M. A.W.S. Fundamental Research Session — Arc Studies and Heat Flow; Bellevue-Stratford Hotel
9:30 A.M. A.W.S. Railroad Session; Bellevue-Stratford Hotel
9:30 A.M. W.A. Mordica Memorial Lecture; Hotel Philadelphian
10:00 A.M. A.I.M.E. (Institute of Metals Division) Session on Brass; Ritz-Carlton Hotel
10:00 A.M. A.I.M.E. (Iron and Steel Division) Session on Iron and Iron Alloys; Ritz-Carlton
11:30 A.M. ⊜ Defense Meeting; Benjamin Franklin Hotel
12:00 M. National Metal Exposition opens; Convention Hall
12:00 M. ⊜ Canadian Luncheon; Benjamin Franklin Hotel
12:15 P.M. A.I.M.E. (Institute of Metals) Executive Committee, Luncheon; Ritz-Carlton
12:15 P.M. A.I.M.E. Committee on Bessemer Steel, Luncheon Meeting; Ritz-Carlton Hotel
1:00 P.M. W.A. National Defense Luncheon; Hotel Philadelphian
2:00 P.M. A.I.M.E. Round Table Discussion on Order-Disorder Phenomena; Ritz-Carlton
2:00 P.M. A.W.S. Fundamental Research Session — Testing Methods; Bellevue-Stratford
2:00 P.M. A.W.S. Aircraft and Automotive Session; Bellevue-Stratford Hotel
2:00 P.M. A.W.S. Structural Session; Bellevue-Stratford Hotel
2:30 P.M. ⊜ National Defense Group Meeting on Higher Alloy Steels (Oil Quenching Steels); Convention Hall
2:30 P.M. ⊜ National Defense Group Meeting on Copper and Its Alloys; Convention Hall
4:00 P.M. W.A. Annual Meeting; Hotel Philadelphian
5:00 P.M. ⊜ Lecture Course, Heat Flow in Metals; Convention Hall

CONSOLIDATED PROGRAM

National Metal Congress

Tuesday Evening, Oct. 21, 1941

7:30 P.M. A.I.M.E. (Institute of Metals and Iron and Steel Divisions) Annual Autumn Dinner; Ritz-Carlton Hotel
7:30 P.M. A.W.S. Fundamental Research Conference; Bellevue-Stratford Hotel
8:00 P.M. National Defense Group Meeting on Stainless and Heat Resisting Steel; Convention Hall
8:00 P.M. Lecture Course, Hardness and Hardness Measurements; Convention Hall
10:30 P.M. National Metal Exposition closes

Wednesday, Oct. 22, 1941

7:30 A.M. Chapter Chairmen's Breakfast; Benjamin Franklin Hotel
9:30 A.M. Annual Meeting and Campbell Memorial Lecture; Benjamin Franklin Hotel
9:30 A.M. A.W.S. Research Session — Structural; Bellevue-Stratford Hotel
9:30 A.M. A.W.S. Automotive and Aircraft Session; Bellevue-Stratford Hotel
9:45 A.M. W.A. Technical Session; Hotel Philadelphian
12:00 M. National Metal Exposition opens; Convention Hall
12:00 M. College Alumni Luncheons; Benjamin Franklin Hotel
12:15 P.M. A.I.M.E. (Iron and Steel Division) Executive Committee Luncheon Meeting; Ritz-Carlton Hotel
2:00 P.M. A.I.M.E. (Institute of Metals Division) Session on Magnesium and Aluminum Alloys; Ritz-Carlton Hotel
2:00 P.M. A.I.M.E. (Iron and Steel Division) Session on Low Alloy Steel; Ritz-Carlton Hotel
2:00 P.M. A.W.S. Resistance Welding Symposium; Bellevue-Stratford Hotel
2:00 P.M. A.W.S. Fundamental Research Session — Metallurgical; Bellevue-Stratford Hotel
2:00 P.M. A.W.S. National Defense Session; Bellevue-Stratford Hotel
2:00 P.M. W.A. Technical Session; Hotel Philadelphian
2:30 P.M. National Defense Group Meeting on High Strength Low Alloy Steels (Weldable Grades for Pressure Vessels, Piping, Ships, Rolling Stock); Convention Hall
5:00 P.M. Lecture Course, Heat Flow in Metals; Convention Hall
7:30 P.M. W.A. Annual Dinner and Stag Smoker
8:00 P.M. National Defense Group Meeting on Inspection of Metals; Convention Hall
8:00 P.M. Lecture Course, Hardness and Hardness Measurements; Convention Hall
10:30 P.M. National Metal Exposition closes

Thursday, Oct. 23, 1941

9:00 A.M. Symposium on Controlled Atmospheres; Benjamin Franklin Hotel
9:00 A.M. Physical Properties Session; Benjamin Franklin Hotel
9:00 A.M. Metallography of Steel Session; Benjamin Franklin Hotel
9:30 A.M. A.W.S. Resistance Welding Session; Bellevue-Stratford Hotel
9:30 A.M. A.W.S. Machinery Session; Bellevue-Stratford Hotel
9:45 A.M. W.A. Technical Session; Hotel Philadelphian
11:30 A.M. Defense Meeting; Benjamin Franklin Hotel
12:00 M. National Metal Exposition opens; Convention Hall
2:00 P.M. A.W.S. Committee Meetings and District and Section Officers' Conference; Bellevue-Stratford Hotel
2:30 P.M. National Defense Group Meeting on Castings (Steel and Iron); Convention Hall
2:30 P.M. National Defense Group Meeting on Bearings; Problems, Conservation and Substitution; Convention Hall
5:00 P.M. Lecture Course, Heat Flow in Metals; Convention Hall
6:00 P.M. National Metal Exposition closes.
7:00 P.M. A.W.S. Annual Banquet; Bellevue-Stratford Hotel
7:30 P.M. Annual Banquet; Benjamin Franklin Hotel

Friday, Oct. 24, 1941

9:00 A.M. Symposium on Controlled Atmospheres; Benjamin Franklin Hotel
9:00 A.M. High Speed Steels Session; Benjamin Franklin Hotel
9:00 A.M. Steel Making and Research Session; Benjamin Franklin Hotel
9:30 A.M. A.W.S. Piping and Pressure Vessels Session; Bellevue-Stratford Hotel
9:30 A.M. A.W.S. Session on Welding of High Alloy Steels; Bellevue-Stratford Hotel
11:30 A.M. Defense Meeting; Benjamin Franklin Hotel
11:30 A.M. A.W.S. Business Meeting and Board of Directors' Luncheon Meeting; Bellevue-Stratford Hotel
12:00 M. National Metal Exposition opens; Convention Hall
2:30 P.M. National Defense Group Meeting on Molybdenum High Speed Steels and Tool Steels; Convention Hall
2:30 P.M. Lecture Course, Heat Flow in Metals; Convention Hall
10:30 P.M. National Metal Exposition and National Metal Congress end.

Technical Meetings

Monday, October 20

9:00 A.M. — Alloy Steels
BALLROOM, BENJAMIN FRANKLIN HOTEL

The Nickel-Molybdenum System
by *F. H. Ellinger*, General Electric Co.

Acicular Structure in Ni-Mo Cast Irons
by *R. A. Flinn*, American Brake Shoe & Foundry Co.

Hot Brittleness of 0.50 Molybdenum Steel
by *Morris Cohen* and *John Chipman*, Massachusetts Institute of Technology

Some Properties of Phosphorus-Titanium Steels
by *C. L. Clark*, Timken Roller Bearing Co.
and *J. W. Freeman*, University of Michigan

Wear Tests on Ferrous Alloys
by *G. F. Comstock*, The Titanium Alloy Mfg. Co.

by *O. W. Ellis*, Ontario Research Foundation

9:00 A.M. — Fabrication
WASHINGTON ROOM, BENJAMIN FRANKLIN HOTEL

The Effect of Microstructure Upon the Work Hardening Characteristics of a 0.74% Carbon Strip Steel
by *N. P. Goss* and *Wm. Brenner, Jr.*, Cold Metal Process Co.

Problems in the Drawability of Deep Drawing Sheets
by *M. Asimow*, Central Metal Products Co.
and *J. N. Crombie*, Carnegie-Illinois Steel Corp.

A Study of Cutting Oils With and Without Added Sulphur
by *O. W. Boston*, University of Michigan
and *J. C. Zimmer*, Standard Oil Development Corp.

Some Properties of Sintered and Hot Pressed Copper-Zinc Powder Compacts
by *C. G. Goetzel*, American Electro Metal Corp.

Homogenization of Copper-Nickel Powder Alloys
by *F. N. Rhines* and *R. A. Colton*, Carnegie Institute of Technology

9:00 A.M. — Research Methods
BETSY ROSS ROOM, BENJAMIN FRANKLIN HOTEL

Magnetic Methods for Determining Carbon in Steel
by *B. A. Rogers*, *Karl Wentzel* and *J. P. Riott*, U. S. Bureau of Mines

Application of Oscillograph to Determination of Cooling Rates of Quenched Steels
by *C. R. Austin*, Pennsylvania State College
R. M. Allen, Carnegie-Illinois Steel Corp.
and *W. G. Van Note*, North Carolina State College

The Influence of Alloying Elements on the Critical Points of Steels as Measured by the Dilatometer
by *R. N. Gillmor*, General Electric Co.

X-Ray Study of the A_3 Point of Pure Iron Using the Geiger-Muller Counter
by *A. P. Wangsgard*, University of Utah

Heat Etching as a General Method for Revealing the Austenite Grain Size of Steels
by *O. O. Miller* and *M. J. Day*, United States Steel Corp.

Tuesday, October 21

9:00 A.M. — Hardenability
WASHINGTON ROOM, BENJAMIN FRANKLIN HOTEL

Hardenability Testing of Low Carbon Steels
by *R. C. Frerichs* and *E. S. Rouland*, Timken Roller Bearing Co.

Hardenability of Shallow Hardening Steels
by *C. B. Post*, *O. V. Greene* and *W. H. Fenstermacher*, Carpenter Steel Co.

The Effect of Carbon Content and Cooling Rate on the Decomposition of Austenite
by *R. F. Thomson* and *C. A. Siebert*, University of Michigan

Properties of Pearlite, Bainite and Spheroidite
by *M. Gensamer*, *E. B. Pearsall*, *W. S. Pellini* and *J. R. Low, Jr.*, Carnegie Institute of Technology

Effects of Initial Structure on Austenite Grain Formation and Coarsening
by *M. Baeyertz*, Carnegie-Illinois Steel Corp.

9:00 A.M. — Stainless Steels
BALLROOM, BENJAMIN FRANKLIN HOTEL

The Influence of Stress on Corrosion Pitting
by *D. J. McAdam, Jr.* and *G. W. Geil*, National Bureau of Standards

Formation of Tin-Iron Alloy During Hot Tinning
by *A. U. Seybolt*, Battelle Memorial Institute

The Role of Nitrogen in 18-8 Stainless Steel
by *H. H. Uhlig*, General Electric Co.

Acceleration of Strain in Heat Resisting Alloys
by *G. R. Brophy* and *D. E. Furman*, International Nickel Co.

Balancing the Composition of Cast 25% Chromium, 12% Nickel Type Alloys
by *J. T. Gow* and *O. E. Harder*, Battelle Memorial Institute

9:00 A.M. — Heat Treatment
BETSY ROSS ROOM, BENJAMIN FRANKLIN HOTEL

Urea Process for Nitriding Steels
by *R. P. Dunn*, Electro Manganese Corp.
W. B. F. Mackay, Royal Canadian Air Force
and *R. L. Dowdell*, University of Minnesota

The Kinetics of Graphitization in White Cast Iron
by *H. A. Schwartz*, National Malleable and Steel Casting Co.

Effects of Small Amounts of Alloying Elements on Graphitization
by *C. R. Austin*, Pennsylvania State College
and *B. S. Norris*, United States Pipe and Foundry Co.

Properties and Structures of Casehardened Steel as Affected by Cooling Practice
by *O. W. McMullan*, Youngstown Sheet and Tube Co.

The Precipitation Reaction in Cold-Rolled Brasses
by *R. H. Harrington* and *T. C. Jester*, General Electric Co.

Educational Courses

5:00 P.M., Monday Through Friday
NO. 300 ROOM, CONVENTION HALL

Heat Flow in Metals
by *J. B. Austin*, U. S. Steel Corp. Research Laboratories

8:00 P.M., Monday Through Wednesday
NO. 400 ROOM, CONVENTION HALL

Hardness and Hardness Measurements
by *S. R. Williams*, Amherst College

Technical Meetings

Wednesday, October 22

9:30 A.M. — Annual Meeting of
BALLROOM, BENJAMIN FRANKLIN HOTEL

1941 Edward de Mille Campbell Memorial Lecture
by *R. F. Mehl*, Carnegie Institute of Technology

Thursday, October 23

Simultaneous Morning Sessions

9:00 A.M. — Controlled Atmospheres
BALLROOM, BENJAMIN FRANKLIN HOTEL

Fundamental Features of Controlled Atmospheres
by *H. W. Gillett* and *B. W. Gonser*, Battelle Memorial Institute

Chemical Equilibrium as a Guide to Control
by *J. B. Austin* and *M. J. Day*, United States Steel Corp.

Prevention of Oxidation Type of Reaction of Ferrous Metals
by *A. G. Hotchkiss* and *H. M. Webber*, General Electric Co.

Prevention of Oxidation Type of Reaction in the Heat Treatment of Copper and Its Alloys
by *E. G. deCoriolis* and *William Lehrer*, Surface Combustion Corp.

Heat Treatment of the Cr-C Stainless Steels
by *W. E. Mahin* and *W. C. Troy*, Westinghouse Electric & Mfg. Co.

9:00 A.M. — Physical Properties
BETSY ROSS ROOM, BENJAMIN FRANKLIN HOTEL

Effect of Strain Rate on Tensile Impact Strength
by *E. R. Parker* and *C. Ferguson*, General Electric Co.

Effect of Grain Size and Heat Treatment Upon Impact Toughness at Low Temperatures
by *S. J. Rosenberg* and *D. H. Gagon*, National Bureau of Standards

Low Temperature Impact Resistant Steel Castings
by *N. A. Ziegler* and *H. W. Northrup*, Crane Co.

Dynamic Hardness Testing of Metals and Alloys at Elevated Temperatures
by *Erich Fetz*, C. O. Jelliff Mfg. Corp

9:00 A.M. — Metallography
WASHINGTON ROOM, BENJAMIN FRANKLIN HOTEL

Microstructure of High Purity Fe-C Alloys
by *T. G. Digges*, National Bureau of Standards

The Structure of Pearlite
by *F. C. Hull*, Westinghouse Electric and Mfg. Co.
and *R. F. Mehl*, Carnegie Institute of Technology

The Interlamellar Spacing of Pearlite
by *G. E. Pellissier*, International Nickel Co.
M. F. Hawkes, Carnegie Institute of Technology
W. A. Johnson, Westinghouse Electric & Mfg. Co.
and *R. F. Mehl*, Carnegie Institute of Technology

The Martensite Thermal Arrest
by *A. B. Greninger*, General Electric Co.

A Study of Martensite Formation by a Photometric Method
by *E. R. Saunders*, Union Carbide & Carbon Corp.
and *J. F. Kahles*, University of Cincinnati

Friday, October 24

Simultaneous Morning Sessions

9:00 A.M. — Controlled Atmospheres
BALLROOM, BENJAMIN FRANKLIN HOTEL

Prevention of Decarburization in Aircraft Engines
by *J. A. Comstock*, Pratt & Whitney Aircraft Division

Methods for Determining the Degree of Carburization or Decarburization
by *N. K. Koebel*, Lindberg Engineering Co.

Surface Effects Accompanying the Heating of Carbon Tool Steel in Oxidizing Atmospheres
by *R. D. Stout* and *Toivo Aho*, Lehigh University

Discussion of Equipment, Instrumentation and Economy
by *E. E. Slowter*, Battelle Memorial Institute

Atmospheric Control in the Heat Treatment of Aluminum Products
by *P. T. Stroup*, Aluminum Co. of America

Atmospheric Control in the Heat Treatment of Magnesium Products
by *C. E. Nelson*, Dow Chemical Co.

9:00 A.M. — High Speed Steels
WASHINGTON ROOM, BENJAMIN FRANKLIN HOTEL

Electrical Resistance Method for the Determination of Isothermal Austenite Transformations
by *F. B. Rote*, International Nickel Co.
W. C. Truckenmiller, A-C Spark Plug Div., General Motors Corp.
and *W. P. Wood*, University of Michigan

The Tempering of Two High Carbon, High Vanadium High Speed Steels
by *B. S. Lement* and *Morris Cohen*, Mass. Inst. of Technology

The Transformation of Retained Austenite in High Speed Steel at Low Temperatures
by *M. P. Gordon* and *Morris Cohen*, Massachusetts Institute of Technology

Study of Dimensional and Other Changes in Various Die Steels Due to Heat Treatment
by *G. M. Butler, Jr.*, Allegheny Ludlum Steel Corp.

Hardening Characteristics of Fe-Co-W Alloy
by *W. P. Sykes*, General Electric Co.

9:00 A.M. — Steel Making
BETSY ROSS ROOM, BENJAMIN FRANKLIN HOTEL

The Over-All Linear Expansion of Three Face-Centered Cubic Metals (Al, Cu, Pb)
by *J. W. Richards*, Mount St. Mary's College

Growth of Shatter Cracks in Steel Rails
by *H. B. Wishart* and *E. P. Epler*, Carnegie-Illinois Steel Corp.
and *R. E. Cramer*, University of Illinois

The Carbon-Oxygen Equilibrium in Liquid Iron
by *Shadburn Marshall*, Remington Arms Co.
and *John Chipman*, Mass. Inst. of Technology

The Solubility of Iron Oxide in Liquid Iron
by *John Chipman*, Mass. Inst. of Technology
and *K. L. Fetters*, Carnegie Inst. of Technology

Rapid Temperature Measurements of Molten Iron and Steel With an Immersion Thermocouple
by *Fulton Holtby*, University of Minnesota

National Defense Group Meetings

Monday, October 20, 1941

On August 18 representatives of the major American engineering societies were called together in Washington by Robert E. McConnell, director of conservation and substitution, Office of Production Management, in order to lay before the engineers of this country the latest available information on the supply and demand for strategic and critical metals. As one part of the informational program requested by him, the ASM has organized eleven conferences on the conservation and substitution of the important industrial metals. They have been scheduled for afternoon and evening; all scientific and technical papers will be read in morning sessions to avoid conflicts.

Monday Afternoon

2:30 P.M. — Low Carbon Alloy Steels (Case Hardening Steels)
BALLROOM, CONVENTION HALL

LEADER: *Gordon T. Williams*
Metallurgist, Deere & Co.
SUMMARIZER: *O. W. McMullan*
Metallurgist, Youngstown Sheet & Tube Co.

Report
from Conservation and Substitution Committee

Commonly Used Alloy Steels That Are Scarce or Unobtainable
by *Walter Hildorf*, Chief Metallurgical Engineer, Timken Steel & Tube Co.

Suggestions About Substitutes That Will Not Run Into Other Bottlenecks
by *E. T. Barron*, Manager, Metallurgical Division, Pittsburgh District, Carnegie-Illinois Steel Corp.

Comparison of Scarce Steels and Substitutes as to Machinability, Speed of Carburization, Hardness of Case, Uniform Hardenability of Case, Strength and Toughness of Core, Nature of Quench, Amount of Distortion During Heat Treating
by *F. E. McCleary*, Metallurgical Engineer, Chrysler Corp.

Possibilities of Flame Hardening, Induction Hardening and Salt Bath Hardening of Substitute Steels
(Speaker to be announced)

Changes in Mechanical Design of a Part to Permit Substitutes
by *H. W. McQuaid*, Assistant Chief Metallurgist, Republic Steel Corp.

General Discussion by the Audience

Questions and Answers

Summary of Important Points
by *O. W. McMullan*
Metallurgist, Youngstown Sheet & Tube Co.

Evening

8:00 P.M. — Manufacture of Shells
ROOM NO. 300, CONVENTION HALL

LEADER: *Arthur F. Macconochie*
Head, Department of Mechanical Engineering, University of Virginia
SUMMARIZER: (To be announced).

Shell Steel
(Speaker to be announced)

Forged Shells
by *F. G. Schranz*, General Manager, Baldwin-Southwark Division

Heat Treatment of Shells
by Col. *H. H. Zornig*
Office of Chief of Ordnance

Sand Blasting of Shells
(Speaker to be announced)

Machining of Shells
by *Ben C. Brosheer*, Associate Editor, *American Machinist*

Cartridge Cases
by *Alan Morris*, Research Engineer, Bridgeport Brass Co.

General Discussion by the Audience

Questions and Answers

Summary of Important Points

8:00 P.M. — Fabrication of Aluminum and Magnesium Base Alloys for Defense Materials
BALLROOM, CONVENTION HALL

LEADER: *E. H. Dix, Jr.*
Chief Metallurgist, Aluminum Co. of America
SUMMARIZER: *Harry Huester*
Metallurgist, Reynolds Metals Co.

Aluminum Castings and Their Heat Treatment
by *B. Clements*, Metallurgist, Wright Aeronautical Corp.

Aluminum Forgings and Their Heat Treatment
by *L. W. Davis*, Chief Metallurgist, Forgings Division, Aluminum Co. of America

Aluminum Structural Shapes and Sheet, and Their Heat Treatment
by *T. W. Bossert*, Assistant Chief Metallurgist, Fabricating Division, Aluminum Co. of America

Welding of Aluminum
by *G. O. Hoglund*, Welding Engineer, Aluminum Co. of America

Machining of Aluminum
by *W. A. Dean*, Research Metallurgist, Aluminum Co. of America

Magnesium Castings
by *Arthur W. Winston*, Director, Metallurgical Department, Dow Chemical Co.

General Discussion by the Audience

Questions and Answers

Summary of Important Points
by *Harry Huester*
Metallurgist, Reynolds Metals Co.

National Defense Group Meetings

Tuesday, October 21, 1941

Simultaneous Afternoon Meetings

2:30 P.M. — Higher Alloy Steels (Oil Quenching Steels)
BALLROOM, CONVENTION HALL

LEADER: *M. A. Grossmann*
Chief Metallurgist, Chicago District, Carnegie-Illinois Steel Corp.

SUMMARIZER: *Harry W. McQuaid*
Consultant, OPM, and Assistant Chief Metallurgist, Republic Steel Corp.

Report
from Conservation and Substitution Committee

Outline of Function of Principal Alloys in Steel
by *E. C. Bain*, Assistant to the Vice-President U. S. Steel Corp.

Commonly Used Alloy Steels That Are Scarce
by *Harry W. McQuaid*, Assistant Chief Metallurgist Republic Steel Corp.

Standardization of Steel Specifications
by *C. L. Warwick*, Consultant Conservation Board, Division of Purchases, OPM

Suggestions About Substitutes That Will Not Run Into Other Bottlenecks
by *M. J. R. Morris*, Chief Metallurgical Engineer Republic Steel Corp.

Evaluating the Hardenability of Steel
by *Walter E. Jominy*, Research Metallurgist Chrysler Corp.

Comparison of Scarce Steels and Substitutes as to Availability and Cost, Machinability and other Manufacturing Properties
by *H. J. French*, Manager, Alloy Steel and Iron Development International Nickel Co., Inc.

Changes in Design, to Permit Substitution
by *Harry W. McQuaid*, Assistant Chief Metallurgist Republic Steel Corp.

General Discussion by the Audience

Questions and Answers

Summary of Important Points
by *Harry W. McQuaid*
Assistant Chief Metallurgist, Republic Steel Corp.

2:30 P. M. — Copper and Its Alloys
ROOM NO. 300, CONVENTION HALL

LEADER: *Harry P. Croft*
Asst. Director of Research, Cleveland Mill Division, Chase Brass & Copper Co.

SUMMARIZER: Maj. *Leslie S. Fletcher*
Frankford Arsenal

Report
from Conservation and Substitution Committee

Elimination of Unnecessary Alloys
by *D. K. Crampton*, Director of Research Chase Brass & Copper Co.

Standardization of Specifications
by *C. L. Warwick*, Consultant Government Conservation Board Division of Purchases, OPM

Use of Temporary Substitutes:

(a) In Diversified Industry
by *W. B. Price*, Chief Chemist and Metallurgist Scovill Mfg. Co.

(b) In the Electrical Industry
by *T. S. Fuller*, Engineer of Materials Schenectady Works Laboratory, General Electric Co.

(c) In Communications Industry
by *Earle E. Schumacher* Bell Telephone Laboratories

Use of Copper Alloys as Alternates for Scarce Metals
by *John R. Freeman*, Manager, Technical Department American Brass Co.

Copper and Its Alloys in Munitions Parts
by Lt. *W. W. Culbertson* Frankford Arsenal

Copper in Iron and Steel for Defense Work
by *J. E. Jackson*, Metallurgical Engineer Copper Iron and Steel Development Association

General Discussion by the Audience

Questions and Answers

Summary of Important Points
by Maj. *Leslie S. Fletcher*
Frankford Arsenal

8:00 P. M. — Evening Session on Stainless and Heat Resisting Steel
BALLROOM, CONVENTION HALL

CHAIRMAN: *A. L. Feild*
Director of Research, Rustless Iron and Steel Corp.

SUMMARIZER: *R. J. McKay*
Chemical Engineer, International Nickel Co., Inc.

Report
from Conservation and Substitution Committee

The Problem of Conservation: -

Substitutes for Decorative Uses
by *C. E. Heussner*, Chrysler Corp.

Use of Alloys of Lower Chromium and/or Nickel

(a) 16% Cr. 1½% Ni
by *Stanley P. Watkins*, Rustless Iron and Steel Corp.

(b) 13% Cr Steels
by *R. A. Lincoln*, Allegheny Ludlum Steel Co.

(c) Use of Reclaimed Scrap
by *Hubert A. Grove*, Republic Steel Corp.

Clad Materials
by *S. L. Hoyt*, Battelle Memorial Institute

Conservation of Heat Resisting Alloys
by *M. A. Hunter*, Driver-Harris Co.

The Problem of Substitution:

Lead
by *R. L. Hallett*, National Lead Co.

Silicon Irons
by *D. E. Jack*, Duriron Co., Inc.

Calorized Irons
by *B. J. Sayles*, The Calorizing Co.

Silicon Cementation
by *Harry K. Ihrig*, Globe Steel Tubes Co.

Quasi-Stainless Steels
by *Russell Franks*
Union Carbide and Carbon Research Laboratories, Inc.

Silver and Platinum Lined Equipment
by *Fred E. Carter*, Baker & Co.

National Defense Group Meetings

Wednesday, October 22, 1941

Afternoon

2:30 P.M. — High Strength Low Alloy Steels (Weldable Grades for Pressure Vessels, Piping, Ships, Rolling Stock)
BALLROOM, CONVENTION HALL

LEADER: Col. *Glenn F. Jenks*
Ordnance Department, U. S. Army

SUMMARIZER: *James C. Hodge*
Vice-President, Wellman Engineering Co.

Report
from Conservation and Substitution Committee

Alloys Available to Give Strength Without Heat Treatment
by *A. B. Kinzel*, Chief Metallurgist
Union Carbide & Carbon Research Laboratories, Inc.

Limits of Alloying Before Weldability Is Impaired
by *Leon C. Bibber*, Welding Engineer
Carnegie-Illinois Steel Corp.

Substitutes for Scarce Alloys
by *B. D. Saklatwalla*, Consultant
Alloys Development Corp.

Substitutions in Various Industries:

(I) Railroad Rolling Stock
by *B. D. Saklatwalla*, Consultant
Alloys Development Corp.

(II) Pressure Vessels, Piping and Bolting
by *J. J. Kanter*, Materials Research Engineer
Crane Co.

(III) Large Forgings
by *F. B. Foley*, Superintendent, Research Department
The Midvale Co.

(IV) Ships' Hulls
by *Paul D. Ffield*, Materials Engineer
Bethlehem Steel Co., Shipbuilding Division

(V) Bridges and Building Skeletons
by *Jonathan Jones*, Chief Engineer
Bethlehem Steel Co.

Welded Pipe and Pressure Vessel Linings
by *Merrill A. Scheil*, Research Metallurgist
A. O. Smith Corp.

General Discussion by the Audience

Questions and Answers

Summary of Important Points
by *James C. Hodge*
Vice-President
Wellman Engineering Co.

Evening

8:00 P.M. — Inspection of Metals
BALLROOM, CONVENTION HALL

LEADER: *John W. W. Sullivan*
Head, Inspection Division, Cleveland Ordnance District

SUMMARIZER: *W. J. Jeffries*
District Chief Engineer, Philadelphia Ordnance District

Principles of Inspection of Non-Ferrous Materials
by *Ernest E. Thum*, Editor
Metal Progress

Principles of Inspection of Ferrous Materials
by *Earl Blaine*, Chief Inspector
E. G. Budd Mfg. Co.

Principles of Aircraft Inspection
by *C. G. Stephens*, Materials Supervisor
Glenn L. Martin Co.

Inspection of Aircraft Engine Materials
by *E. S. Marks*, Quality Engineer
Pratt & Whitney Aircraft Division

Army Ordnance Inspection
by Brig. Gen. *R. H. Somers*
Ordnance Department, U. S. Army

Navy Ordnance Inspection
Lt. Com. *C. A. Misson*, U. S. N.
Inspector of Ordnance, Midvale Co.

Marine Construction Inspection
by Capt. *Ralph T. Hanson*, U. S. N.
Supervisor of Shipbuilding, Cramp Shipbuilding Co.

Training of Inspectors
by Capt. *K. J. Soderberg*, Civilian Personnel Division
Office of Chief of Ordnance, U. S. A.

General Discussion

Questions and Answers

Summary of Important Points
by *W. J. Jeffries*
District Chief Engineer
Philadelphia Ordnance District

Non-Technical Talks on

General Needs of National Defense

ALL MEETINGS HELD AT 11:30 A. M. — BALLROOM, BENJAMIN FRANKLIN HOTEL

Monday, October 20

Major General Jacob L. Devers
In Command of Armored Troops, U. S. Army

Tuesday, October 21

Lieutenant Commander J. C. Crommellin
Bureau of Aeronautics, U. S. Navy

Thursday, October 23

Rear Admiral Thomas T. Craven, U. S. N.

Friday, October 24

A Representative of the Office of Production Management

National Defense Group Meetings

Thursday Afternoon, October 23, 1941

2:30 P.M. — Alloy Castings (Steel and Iron)

BALLROOM, CONVENTION HALL

CHAIRMAN: *A. L. Boegehold*
Head, Metallurgical Department, General Motors Research Laboratories

SUMMARIZER: *C. H. Lorig*
Battelle Memorial Institute

Report
from Conservation and Substitution Committee

Function of Ni, Cr, and V That Are Scarce
by *A. W. Demmler*, Vanadium Corp. of America

Function of Manganese That Is Probably Obtainable
by *Fred Grotts*, Fort Pitt Steel Castings Co.

Function of Silicon, Titanium and Phosphorus
by *G. F. Comstock*, Titanium Alloy Mfg. Co.

Function of Copper
by *J. E. Jackson*, Copper Iron & Steel Development Asso.

Function of Molybdenum and Utilization of Classified Scrap and Alloy Pig Iron
by *Victor Crosby*, Climax Molybdenum Corp.

Ultimate Conservation Due to Over-All Economies of Better Metal
by *Victor Crosby*, Climax Molybdenum Corp.

Situation in Various Important Industries:

(I) Automotive
by *Robert Schenck*, Buick Motor Car Co.

(II) Railroad
by *Samuel Z. Krumm*, The Buckeye Steel Castings Co.

(III) Power
by *Norman L. Mochel*, Westinghouse Electric & Mfg. Co.

(IV) Chemical and Petroleum
by *Francis B. Foley*, The Midvale Co.

(V) Agricultural Machinery
by *Hyman Bornstein*, Deere & Co.

2:30 P.M. — Bearings

ROOM NO. 400, CONVENTION HALL

LEADER: *O. E. Harder*
Assistant Director, Battelle Memorial Institute,

SUMMARIZER: *A. Allan Bates*
Manager, Chemical & Metallurgical Dept. Westinghouse Electric & Mfg. Co.

Report
from Conservation and Substitution Committee

Replacing Tin-Base Babbitts by Lead-Base Babbitts
by *Carl E. Swartz*, Metallurgist
Cleveland Graphite Bronze Co.

Bronze Bushings
by *E. R. Darby*, Director of Research
Federal Mogul Corp.

Problems and Substitutes in Powder Metallurgy Bearings
by *R. P. Koehring*, Metallurgist
Moraine Products Division, General Motors Corp.

Cadmium-Base Bearings
by *C. F. Smart*, Metallurgist
Pontiac Motor Division, General Motors Corp.

Silver Bearings
by *E. A. Ryder*, Consulting Engineer
Pratt & Whitney Aircraft Div.

Bearing Substitutes in the Automotive Industry
by *Arthur F. Underwood*, Head Mechanic
Research Laboratories Division, General Motors Corp.

Problems in Aircraft Bearings
(Speaker to be announced)

The Use of Iron-Copper Bearings
by *A. J. Langhammer*, Amplex Division
Chrysler Corp.

General Discussion by the Audience

Questions and Answers

Summary of Important Points
By *A. Allan Bates*
Manager, Chemical & Metallurgical Dept., Westinghouse Electric & Mfg. Co.

2:30 P. M. Friday Afternoon, October 24, 1941

Molybdenum High Speed Steels and Tool Steels

BALLROOM, CONVENTION HALL

LEADER: *Bradley Stoughton*
Chief, Heat Treatment Equipment Unit, Tools Section, OPM

SUMMARIZER: *G. V. Luerssen*
Metallurgist, Carpenter Steel Co.

Report on Alloying Elements
from Conservation and Substitution Committee

OPM Committee Report on the Heat Treatment of Molybdenum High Speed Steel:

(I) Operations
by *Norman I. Stotz*, Metallurgist
Universal-Cyclops Steel Corp., Chairman

(II) Furnaces and Controlled Atmospheres
by *C. I. Hayes*, President
C. I. Hayes, Inc., Chairman

(III) Salt Baths
by *A. F. Holden*, President
A. F. Holden Co., Chairman

Tool Steels
by *James P. Gill*, Chief Metallurgist
Vanadium-Alloys Steel Co.

General Discussion by the Audience

Questions and Answers

Summary of Important Points
by *G. V. Luerssen*
Metallurgist, Carpenter Steel Co.

American Welding Society Program

Sunday, October 19

5:00 to 7:00 P.M. — President's Reception
NORTH GARDEN, BELLEVUE-STRATFORD HOTEL

Monday, October 20

9:30 A.M. — Presentation of Medals and Prizes
ROSE GARDEN, BELLEVUE-STRATFORD HOTEL

10:15 A.M. — Plain Carbon and Low Alloy Steels
ROSE GARDEN, BELLEVUE-STRATFORD HOTEL

The Specification of Weldability of Steels
by *A. B. Kinzel* } Union Carbide and Carbon Research Laboratories

Weldability Tests of Nickel Steels
by *C. E. Jackson* and *G. G. Luther* } Naval Research Laboratory

Weldability of Steels
by *W. H. Bruckner*, University of Illinois

2:00 P.M. — Non-Ferrous Research
ROSE GARDEN, BELLEVUE-STRATFORD HOTEL

Quality of Welds in Monel, Nickel and Inconel
by *F. G. Flocke* and *K. M. Spicer* } The International Nickel Co., Inc.

The Flow of Metal in Brazing Aluminum
by *M. A. Miller*, Aluminum Research Laboratories

Welding of Copper
by *A. P. Young*, Michigan College of Mining & Technology

The Spot Welding of Nickel, Monel and Inconel
by *W. F. Hess* and *Albert Muller* } Rensselaer Polytechnic Institute

2:00 P.M. — Shipbuilding Session
SOUTH GARDEN, BELLEVUE-STRATFORD HOTEL

Riveted Vs. Welded Smoke Pipes
by *H. O. Klinke*, U. S. Navy Yard

Machine Flame Cutting in Shipbuilding
by *E. R. McClung* and *H. L. Wagener* } New York Shipbuilding Corp.

Survey of Welding and Cutting in Ship Construction
by *F. G. Outcalt* and *J. M. Keir* } The Linde Air Products Co.

Welding Applications in Naval Machinery
by *H. W. Hiemke* and *J. D. Bert* } Navy Department Bureau of Ships

2:00 P.M. — Training Session
NORTH GARDEN, BELLEVUE-STRATFORD HOTEL

Training of Welding Operators
Discussion led by *A. G. Bissell*, Bureau of Ships, U.S.N.

A.W.S. Minimum Requirements for the Training of Welding Operators
by *L. M. Dalcher*, Secretary of Committee

Training Welders for National Defense
by *James A. Waln* { Defense Training Program U. S. Office of Education

Training of Oxy-Acetylene Welding and Cutting Operators
by *D. E. Roberts*, International Acetylene Association

7:30 P.M. — Industrial Research Conference
BELLEVUE-STRATFORD HOTEL

9:00 P.M. — Educational Conference
BELLEVUE-STRATFORD HOTEL

Tuesday, October 21

9:30 A.M.—Fundamental Research
SOUTH GARDEN, BELLEVUE-STRATFORD HOTEL

Magnetic Arc Blow
by *C. H. Jennings* and *A. B. White* } Westinghouse Electric & Mfg. Co.

Metal Transfer in the Metallic Arc
by *L. J. Larson*, Consulting Engineer

Heat Flow in Arc Welding
by *E. M. Mahla*, *M. C. Rowland*, *C. A. Shook* and *G. E. Doan* } Lehigh University

9:30 A.M. — Railroad Session
ROSE GARDEN, BELLEVUE-STRATFORD HOTEL

Welding as Applied to Locomotives
by *James Partington*, American Locomotive Co.

Design of the World's Largest Welded Flat Car
by *H. M. Priest*, U. S. Steel Corp.

Welding Locomotives
by *A. J. Raymo*, Baldwin Locomotive Co.

Pressure Butt Welding of Railroad Rails
by *Lem Adams*, Oxweld Railroad Service Co.

2:00 P.M. — Testing Methods
NORTH GARDEN, BELLEVUE-STRATFORD HOTEL

Photography of Fusion Welds
by *W. T. Tiffin*, University of Oklahoma

Evaluating Welded Joints
by *W. F. Hess*, Rensselaer Polytechnic Institute

Methods of Testing Spot Welds
by *R. E. Bowman*, War Dept., Air Corps

Thermal Gradients in Spot-Welding Electrodes
by *F. R. Hensel*, *E. I. Larsen* and *E. F. Holt* } P. R. Mallory & Co.

2:00 P.M. — Aircraft and Automotive Session
ROSE GARDEN, BELLEVUE-STRATFORD HOTEL

Automotive Welding
by *S. M. Spice*, Buick Motor Division
Vaugn Fegley, A-C Spark Plug Co.
and *L. M. Skidmore*, General Motors Institute of Technology

Aluminum Alloy Spot Welding
by *P. H. Merriman*, The Glenn L. Martin Co.

Welding in the Aircraft Industry
by *F. M. Smith*, Stout Skycraft Corp.

Condenser Discharge Welding of Aluminum Alloys
by *John W. Dawson*, Raytheon Mfg. Co.
and *B. L. Wise*, Federal Machine & Welder Co.

2:00 P.M. — Structural Session
SOUTH GARDEN, BELLEVUE-STRATFORD HOTEL

Structural Welding
by *Van Rensselaer P. Saxe*, Consulting Engineer

Design of a Welded Bridge
by *G. T. Horton*, Chicago Bridge & Iron Co.

Adapting Construction Methods to Welding
by *LaMotte Grover*, Air Reduction Sales Co.

Cleveland Liquefied Gas Storage Tanks
by *J. O. Jackson*, Pittsburgh-DesMoines Steel Co.

Bridge Welding
by *T. H. Gardner*, Florida East Coast Railway

7:30 P.M. — Fundamental Research Conference
BELLEVUE-STRATFORD HOTEL

American Welding Society Program

Wednesday, October 22

9:30 A.M. — Research Session — Structural
SOUTH GARDEN, BELLEVUE-STRATFORD HOTEL

Tests of Miscellaneous Welded Building Connections
by *Bruce Johnston* and *G. R. Deits* } Lehigh University

Welded Connections for Axially Loaded Members
by *G. J. Gibson* and *B. T. Wake* } American Bridge Co.

9:30 A.M. — Automotive and Aircraft Session
ROSE GARDEN, BELLEVUE-STRATFORD HOTEL

Welding in Aircraft Construction and Maintenance
by *A. K. Seemann*, The Linde Air Products Co.

Management Control of Aircraft Design and Welding
by *J. P. Dods*, Summerill Tubing Co.

A Survey of Aircraft Resistance Welding Equipment
by *L. P. Wood*, Curtiss-Wright Corp., Airplane Division

2:00 P.M. — Resistance Welding Symposium
SOUTH GARDEN, BELLEVUE-STRATFORD HOTEL

Properties of the Condensor Discharge Spot Welds
by *G. S. Mikhalapov* and *T. F. Falls* } Taylor Winfield Corp.

Pulsation Welding of Heavy Structures
by *O. C. Frederick* and *R. P. McCants* } General Electric Co.

Electrical Characteristics of Resistance Welders
by *J. H. Cooper*, Taylor Winfield Corp.

Power Control
by *H. R. Crago*, General Electric Co.

Forging Welding
by *L. M. Benkert*, Progressive Welder Co.

Spot Welding Control and Supervision
by *J. R. Fetcher*, E. G. Budd Mfg. Co.

2:00 P.M. — Fundamental Metallurgy
NORTH GARDEN, BELLEVUE-STRATFORD HOTEL

The Effect of Plate Temperature and Variable Wind Velocities on Welds
by *John L. Miller*, Firestone Tire & Rubber Co.
and *E. L. Koehler*, Illinois Institute of Technology

Welding Aluminum Containing Steels
by *C. E. Sims* and *F. B. Dahle* } Battelle Memorial Institute

Notch Sensitivity of Welds Under Repeated Loading
by *H. L. Daasch*, University of Vermont

The Tee Bend Test to Determine Weldability
by *G. A. Ellinger*, Bureau of Standards
A. G. Bissell, Bureau of Ships, Navy Dept.
and *M. L. Williams*, Bureau of Standards

2:00 P.M. — National Defense Session
ROSE GARDEN, BELLEVUE-STRATFORD HOTEL

Training Brazing Instructors for Defense
by *Leo Edelson*, Handy & Harman

Billet Cutting for Steel Forgings
by *H. E. Rockefeller*, The Linde Air Products Co.

Machine Cutting in National Defense Work
by *R. F. Helmkamp* and *A. H. Yoch* } Air Reduction Sales Co.

Some Radiographic Aspects of Aluminum Spot Welds
by *Robert C. Woods* and *S. L. Rich* } Bell Aircraft Corp.

Thursday, October 23

9:30 A.M. — Resistance Welding Session
SOUTH GARDEN, BELLEVUE-STRATFORD HOTEL

Surface Polish and Contact Resistance
by *W. B. Kouwenhoven* and *J. Tampico* } Johns Hopkins University

Structural Spot Welding Consistency Control Methods
by *A. M. Unger*, Pullman-Standard Car Mfg. Co.

Electrical Measurement of Electrode Pressure During Spot Welding
by *W. F. Hess* and *L. Daniel Rankle* } Rensselaer Polytechnic Institute

9:30 A.M. — Machinery Session
ROSE GARDEN, BELLEVUE-STRATFORD HOTEL

Flame Hardening Internal and External Round Surfaces
by *Stephen Smith*, Air Reduction Sales Co.

Uses of Flame Hardening in Machine Tool Production
by *A. L. Hartley*, R. K. LeBlond Machine Tool Co.

Welding From the Foundryman's Point of View
by *J. J. Curran* and *T. H. Booth* } Walworth Co.

2:00 P.M. — Committee Meetings and District and Section Officers Conference
BELLEVUE-STRATFORD HOTEL

7:00 P.M. — Annual Banquet
BELLEVUE-STRATFORD HOTEL

Friday, October 24

9:30 A.M. — Piping and Pressure Vessels
SOUTH GARDEN, BELLEVUE-STRATFORD HOTEL

Flame Preheating and Stress-Relieving Arc Welded High Pressure Pipe Lines
by *P. T. Onderdonk* and *Werner Peterson* } Consolidated Edison Co. of New York

Welding Pressure Vessels, Tanks and Heat Exchangers
by *H. B. Schlosser*, Edge Moor Iron Works

Radiographic Examination of Heavy Plate
by *O. R. Carpenter*, Babcock & Wilcox Co.

9:30 A.M. — Welding of High Alloy Steels
ROSE GARDEN, BELLEVUE-STRATFORD HOTEL

Hardness Measurements on Rolling Steel That Contained Welds
by *J. T. Phillips*, Foster Wheeler Co.

The Shotweld Process of Welding 18-8 Stainless Steel
by *Joseph Winlock* and *J. J. MacKinney* } E. G. Budd Mfg. Co.

11:30 A.M. — Business Meeting and Board of Directors Luncheon Meeting
BELLEVUE-STRATFORD HOTEL

American Institute of Mining and Metallurgical Engineers

Technical Program

Monday, October 20

9:00 A.M. — Registration
PALM COURT, RITZ-CARLTON HOTEL

10:00 A.M. — Copper and Tin Alloys
(*Institute of Metals Division*)
BALLROOM, RITZ-CARLTON HOTEL

Rates of High Temperature Oxidation of Dilute Copper Alloys
by *F. N. Rhines*, Carnegie Institute of Technology
W. A. Johnson, Westinghouse Research Laboratories
and *W. A. Anderson*, Carnegie Institute of Technology

Effect of Columbium on Some Annealing Characteristics of Copper and 80-20 Cupro-Nickel
by *A. U. Seybolt*, Battelle Memorial Institute

Recrystallization and Precipitation on Aging of Tin-Bismuth Alloys
by *J. E. Burke*, Norton Co.
and *C. W. Mason*, Cornell University

The Ferromagnetic Nature of the Beta Phase in the Copper-Manganese-Tin System
by *L. A. Carapella*, Naval Research Laboratory
and *Ralph Hultgren*, University of California

10:30 A.M.—Physical Chemistry of Steel Making
(*Iron and Steel Division*)
FRENCH ROOM, RITZ-CARLTON HOTEL

Silicon: Oxygen Equilibria in Liquid Iron
by *C. A. Zapffe* and *C. E. Sims* — Battelle Memorial Institute

Silicon Monoxide
by *C. A. Zapffe* and *C. E. Sims* — Battelle Memorial Institute

12:15 P.M. — Luncheon Meeting
Committee on Physical Chemistry of Steel Making
SUPPER ROOM NO. 1, RITZ-CARLTON HOTEL

2:00 P.M. — Physical Metallurgy
BALLROOM, RITZ-CARLTON HOTEL

Theory of Lattice Expansion Introduced by Cold Work
by *Clarence Zener*, State College of Washington

Rapid Tension Tests Using the Two-Load Method
by *A. V. de Forest*, *C. W. MacGregor* and *A. R. Anderson* — Massachusetts Institute of Technology

A New Method for the Determination of Stress Distribution in Thin-Walled Tubing
by *G. Sachs* and *G. Espey* — Case School of Applied Science

Tuesday, October 21

10:00 A.M. — Session on Brass
(*Institute of Metals Division*)
BALLROOM, RITZ-CARLTON HOTEL

Effect of Cold Work and Annealing upon Internal Friction of Alpha Brass
by *Clarence Zener* and *Howard Clarke* — State College of Washington
and *Cyril Stanley Smith*, American Brass Co.

Strength Distribution in Sunk Brass Tubing
by *G. Sachs*, *G. Espey* and *G. B. Kasik* — Case School of Applied Science

Residual Stress in Sunk Cartridge Brass Tubing
by *G. Sachs* and *G. Espey* — Case School of Applied Science

Micrographic Observations of Slip Lines in Alpha Brass
by *R. G. Treuting* and *R. M. Brick* — Yale University

10:00 A.M. — Iron and Iron Alloys
(*Iron and Steel Division*)
FRENCH ROOM, RITZ-CARLTON HOTEL

A Magnetic Determination of the A_3 Point
by *B. A. Rogers* and *K. O. Stamm* — Bureau of Mines

The Instability of Low-Expansion Iron-Nickel-Cobalt Alloys
by *Irvin R. Kramer* and *Francis M. Walters, Jr.* — Naval Research Laboratory

Analysis of Mechanical Properties of Heat Treated Steels
by *J. S. Marsh*, Alloys of Iron Research

The Evaluation of Ductility of Steels for Welding
by *A. B. Kinzel* — Union Carbide & Carbon Research Laboratories

12:15 P.M. — Luncheon Meetings

Executive Committee, Institute of Metals Division
SUPPER ROOM NO. 1, RITZ-CARLTON HOTEL

Committee on Bessemer Steel
SUPPER ROOM NO. 3, RITZ-CARLTON HOTEL

2:00 P.M. — Round Table Discussion
BALLROOM, RITZ-CARLTON HOTEL

Order-Disorder Phenomena
William B. Shockley, Bell Telephone Laboratories
Discussion Leader

7:30 P.M. — Annual Autumn Dinner
BALLROOM, RITZ-CARLTON HOTEL

Building Combat Tanks for the United States Army
by *George K. Bradfield, Jr.* — General Superintendent, Ordnance Division, American Car and Foundry Co.

Wednesday, October 22

12:15 P.M. — Luncheon Meeting
Executive Committee, Iron and Steel Division
SUPPER ROOM NO. 3, RITZ-CARLTON HOTEL

2:00 P.M. — Magnesium and Aluminum Alloys
(Institute of Metals Division)
FRENCH ROOM, RITZ-CARLTON HOTEL

Relief of Residual Stress in Some Aluminum Alloys
by *L. W. Kempf* and *K. R. Van Horn*, Aluminum Co. of America

Preferred Orientation in Rolled Magnesium
by *P. W. Bakarian*, Dow Chemical Co.

Corrosion Studies of Magnesium and Its Alloys
by *J. D. Hanawalt*, *C. E. Nelson* and *J. A. Peloubet*, Dow Chemical Co.

2:00 P.M. — Low Alloy Steel
(Iron and Steel Division)
BALLROOM, RITZ-CARLTON HOTEL

Mechanical Properties of Iron-Manganese Alloys
by *F. M. Walters, Jr.*, *I. R. Kramer* and *B. M. Loring*, Naval Research Laboratory

Influence of Cr and Mo on 0.35% C Steel
by *R. F. Miller* and *R. F. Campbell*, U. S. Steel Corp.

The S-Curve of a Chromium-Nickel Steel
by *Blake M. Loring*, Naval Research Laboratory

The Wire Association

[A registration fee of $5.00 is required. Admission will be by badge only.]

Monday, October 20

10:30 A.M. — Directors' Meeting
HOTEL PHILADELPHIAN

12:00 M. — Luncheon Program Committee
HOTEL PHILADELPHIAN

2:30 P.M. — First Technical Session
HOTEL PHILADELPHIAN

Opening Address
by *F. A. Westphal*, Sheffield Steel Corp.
past president of the Wire Association

The Cable Industry in National Defense
by *Kenneth S. Wyatt*, Phelps Dodge Copper Products Corp.

Activities of the U. S. Army Air Corps
Sound Motion Picture

Tuesday, October 21

9:30 A.M. — Second Technical Session
HOTEL PHILADELPHIAN

The Mordica Memorial Lecture
by *Kenneth B. Lewis*, Consulting Wire Mill Engineer

Steel for the Ages
Sound Motion Picture by Allegheny Ludlum Steel Corp.

1:00 P.M. — National Defense Luncheon
HOTEL PHILADELPHIAN

Addresses
by Brigadier General *A. W. N. Schulz*
Rear Admiral *Wat Tyler Cluverius*
A. A. Stockdale, National Association of Manufacturers
and *Charles I. Gragg*, Office of Production Management

4:00 P.M. — Annual Meeting
HOTEL PHILADELPHIAN

Wednesday, October 22

9:45 A.M. — Third Technical Session
HOTEL PHILADELPHIAN

The Effects of Microstructure on the Galvanizing Characteristics of Steel
by *R. W. Sandelin*, Atlantic Steel Co.

High Speed Rotary Knitting Machine for Covering Electrical Conductors
by *S. E. Brillhart*, Western Electric Co.

A Brief Discussion of the Manufacture of Steel for Arc Welding Electrodes
by *C. W. Garrett*, Jones & Laughlin Steel Corp.

2:00 P.M. — Fourth Technical Session
HOTEL PHILADELPHIAN

Stainless Wire for the Aircraft Industry
by *J. K. Findley*, Allegheny Ludlum Steel Corp.

Diamond Dies for the High Speed Drawing of Copper Wire
by *H. N. Padowicz*, Western Electric Co.

Electrolytic Zinc Coated Wire
by *L. H. Winkler*, Bethlehem Steel Co.

7:30 P.M. — Annual Dinner and Stag Smoker
HOTEL PHILADELPHIAN

Thursday, October 23

9:45 A.M. — Fifth Technical Session
HOTEL PHILADELPHIAN

Time, Temperature and Size in the Heating of Steel Wire
by *R. R. Tatnall*, Wickwire Spencer Steel Co.

Production of Commercial Bronze Screen Cloth Wire
by *B. H. McGar*, Chase Brass & Copper Co., Inc.

Activities of the U. S. Army Air Corps
Sound Motion Picture

11 Years ago HOLDEN announced a high speed bath for MOLY steels

October 25, 1937
STEEL
PRODUCTION • PROCESSING • DISTRIBUTION • USE
FOR FORTY-EIGHT YEARS—IRON TRADE REVIEW
A HIGH SPEED BATH for 'Moly'
And now, following two years of careful development, The A. F. Holden Company presents a newly perfected High Speed Bath for molybdenum as well as tungsten high speed tool steels. Hardening of high speed steel without decarburization no longer remains a problem to the manufacturer and user. "Moly" whose popularity has increased with the scarcity of tungsten, can be successfully hardened without decarburization or change in size. The important part in this new development is the HOLDEN CERAMIC POT which produces scale free work with maximum hardness and an assured savings of, from 10 to 30 per cent.
Processing Time Reduced 50%
This new equipment is controlled and sold exclusively by The A. F. Holden Company. Holden Engineers can save you from $500 to $5000 in the next twelve months.
A new folder describing the process is available on request.
Write or Write Us Today
A. F. HOLDEN COMPANY
New Haven
Conn.

Today..

8 Leading High Speed Tool Manufacturers

use HOLDEN BATHS....SAL-WAY Steel Treating Company, Detroit, Mich., have used Holden Baths over 5 years....Today they have a personnel of 50 people....harden one to three tons of HIGH SPEED STEELS daily....use HOLDEN BATHS EXCLUSIVELY!

THE A. F. HOLDEN COMPANY, New Haven, Conn.

ther Wheelco "Radio Principle" Instruments will be on display

Again Wheelco pioneers an advancement in control instrumentation with the presentation of this new series of flush-mounting temperature controllers. New features and conveniences have been combined with the *Proved-in-Service Superiority* of the "Radio Principle" control system.

Unlike any other control instruments on the market, these new Wheelco Controllers provide • interchangeability of all component parts interchangeability of scale ranges • ready accessibility of all parts for individual checking • setting devices which may be mounted within the instrument case and locked as a precaution against sabotage.

These features, and many others, are plus values added to the instantaneous control afforded by the "Radio Principle"—the control standard in industry since its introduction in 1935. An unlimited number of control combinations are available.

Be sure to see these instruments at the Metal Show.

Specifications: Height—18"

Width—11½"

Depth—11⅞"

Temperature Ranges—0° to 3600° F., or equivalent °C.

Wheelco Instruments Co.
HARRISON AND PEORIA STREETS • • • CHICAGO, ILLINOIS

CAPACITROL

Indicating millivoltmeter combined with "Radio Principle" Control.

POTENTIO-TROL

"Radio Principle" Control combined with potentiometric temperature measurement.

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Indicating millivoltmeter combined with temperature and limiting control.

RECORDING THERM-OTROL

Recording Thermometer Controller for temperatures up to 1000° F.

PROGRAM CONTROL

Automatic control for any heating or cooling cycle.

FLAME-OTROL

Combustion safety control for all types of fuel.

REMOTE CONTROLS

Suitable for almost all control applications.

PORTABLE POTENTIOMETER

Checking instrument for laboratory and plant.

SURFACE PYROMETER

For measuring temperatures on all types of surfaces.

HEAT-EYE

Radiation type thermocouple for extremely exacting applications.

SEE US IN BOOTH 41

DEFENSE BONDS GIVEN AWAY

A $25.00 Defense Bond will be given away each day of the show. A $50.00 Bond will be the prize on the closing day. Request complete details in Booth 41.

Personals

Sidney D. Williams ⊜, formerly vice-president in charge of steel sales, Copperweld Steel Co., has been made executive vice-president in charge of the Warren, Ohio, division. **William B. Klee, Jr.** ⊜, assistant secretary, has been made assistant to the executive vice-president.

Joseph M. Keating ⊜ has received his B. S. in mining and metallurgical engineering from University of Wisconsin, and is now in charge of time study for the Spring City Foundry, the Waukesha, Wis., branch of Grede Foundries.

L. P. Flesch ⊜, formerly with Youngstown Sheet & Tube Co., East Chicago, Ind., is now with Allison Engineering Co., Indianapolis.

George B. Waterhouse, past-president ⊜ and professor of metallurgy, Massachusetts Institute of Technology, is now stationed at Washington as technical consultant in the Steel Section of the Office of Production Management.

Albert B. Castro ⊜ has been commissioned as ensign, U. S. N. R., and is on active duty with a temporary assignment to the Inspectors Ordnance School, Navy Yard, Washington, D. C.

A. P. Bellinghausen ⊜ has been placed in charge of a staff of Army ordnance inspectors at Atlas Imperial Diesel Engine Co., representing the Chicago Ordnance District.

Harold A. Andersen ⊜ is working in the sales engineering department on development work in plastics with Mine Safety Appliances Co., Pittsburgh.

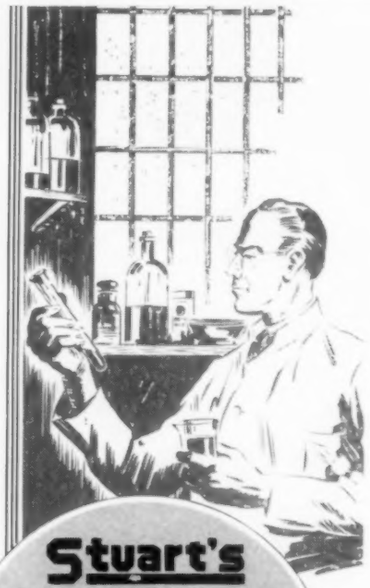
Shadburn Marshall ⊜ finished graduate work at M. I. T. in June and is now research metallurgist, Remington Arms Co., Bridgeport, Conn.

Edward L. F. Engelhard ⊜, formerly supervisor of pyrometers at Driver-Harris Co., is now pyrometer technician in charge at Wright Aeronautical Corp.'s three Paterson district foundries.

Appointed research engineer on the staff of Battelle Memorial Institute, Columbus, Ohio: **Austin Hiller** ⊜, formerly special observer on plant development work in the metallurgical department of the Duquesne Works, Carnegie-Illinois Steel Corp.

Stephen F. Rossiter ⊜, formerly in the metallurgical department of Bethlehem Steel Co., in Lackawanna, N. Y., is now assistant metallurgist to the inspector of naval aircraft, Pratt & Whitney Aircraft Division, East Hartford, Conn.

The FIRST CUTTING COMPOUND *Developed Especially for* CARBIDE *and other* VERY HIGH SPEED CUTTING TOOLS



Stuart's SOLVOL AQUAMIX Liquid Cutting Compound

Try It Quickly and See The Difference

THE rapidly increasing use of carbide and other high speed tools emphasizes the immediate importance of this original type of cutting fluid. STUART'S SOLVOL Liquid Cutting Compound was developed especially for this exact condition. Where operations run "too hot" for properly applied straight cutting oils — and where ordinary soluble cutting oils or soluble paste compounds fail to produce satisfactory finish or tool life — that's the place for this original Stuart Oil development.

WIRE TODAY for working sample — FREE to any industrial concern working on defense orders. To assure proper application please tell us name of part, stock, machine and cutting operations.

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● Visit us in Booth C-1, National Metal Congress, Philadelphia, Oct. 20-24

★ *If you would rather see a photo-micrograph, a bunch of gears, or a flock of furnaces, let us know and we'll fix it.*

Remember the address, "One Grand Mermaid" ★

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IT'S EASY TO SEE WHY LARGE AND SMALL CONCERNS ARE TURNING TO METLAB FOR THEIR HEAT TREATING IN DEFENSE WORK

Results:—

(1) Immediate service in furnaces that are ready.
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LARGEST

COMMERCIAL HEAT TREATERS

IN THE EAST

BOOTH 39

A NEW KIND OF EXHIBIT!

Personals

Promoted: **Richard P. Swartz,** vice-president of Crown Can Co., Philadelphia, to the special post of assistant to the president.

Charles R. Pollock has assumed charge of sales and service for Mahr. Mfg. Co. in the Detroit district.

Donald L. Colwell has taken a temporary leave of absence from the Paragon Die Casting Co. and the Elmer E. Mills Corp. to accept an appointment in the Conservation Section of the Office of Production Management, Washington, D. C.

Transferred by Aluminum Co. of America; **Lewis P. Wilson** from the general technical laboratory in Cleveland to the Detroit plant.

Ralph Parkman is now associated with the Crucible Steel Co. of America, working in the eastern research laboratory of the Atha Works in Harrison, N. J.

Milton C. Parsons is with American Steel and Wire Co. in Duluth, Minn., as a technical apprentice.

Victor H. Lawrence, formerly assistant to the executive vice-president of Alan Wood Steel Co., Conshohocken, Pa., has become associated with Otis Steel Co., Cleveland, as assistant to the president.

Frank E. Weise, Jr. has been transferred from the Bethlehem plant of Bethlehem Steel Co. to the Williamsport Division of the Steelton plant, as a metallurgical engineer working in the wire mill.

Otto W. Winter, formerly factory manager of the Columbus McKinnon Chain Corp., has been appointed vice-president in charge of manufacturing of the Republic Drill and Tool Co., Chicago.

W. H. MacMillan, formerly with Crucible Steel Co. of America, is now metallurgist for the Remington Arms Co., Bridgeport, Conn.

Thomas C. Evans has been graduated from Pennsylvania State College and is now assistant metallurgist at Remington Arms Co., Bridgeport, Conn.

David W. McDowell, Jr. has joined the Navy Air Corps and is at present in training in Jacksonville, Fla.

John E. Dorn, formerly assistant professor at the University of California, is now research metallurgist with Dow Chemical Co., Midland, Mich.

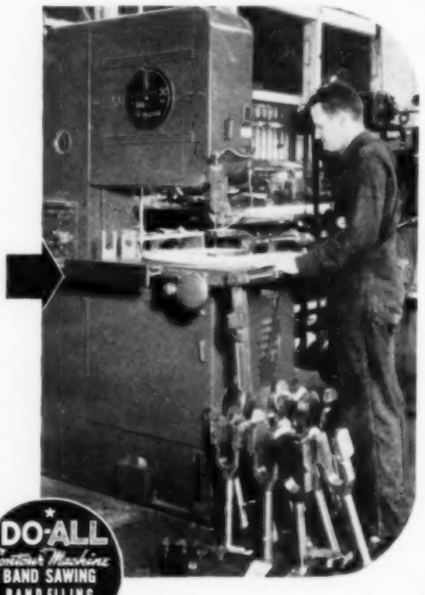
Richard D. Manning is now employed as junior metallurgist for the Thomas Steel Co., Warren, Ohio.

DoAll "SHORT CUT" Metal Worker

Rush that job! Holding up production waiting for it!

Every day is costing us money!

—When customers write and wire like that, it's high time to get a DoAll, today's greatest time saver in metal working plants everywhere.

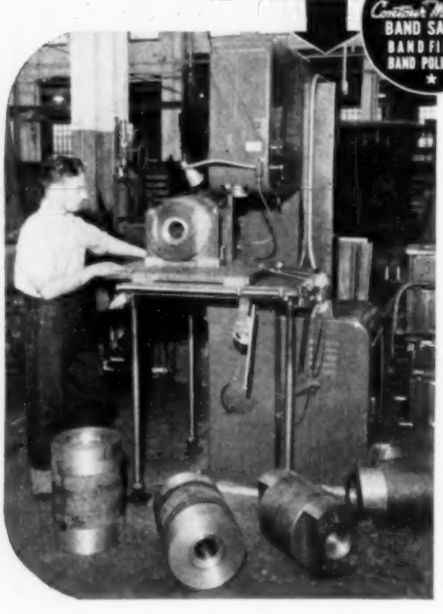


1/8 FORMER TIME

Connecting Rods for Diesel Engines made in less than 1 hour each at Sumner Iron Works, Everett, Wash. Former time—8 hours each.

1/3 FORMER TIME

Wrist pins for Diesel Engines made from 45 carbon steel in 2 hours, 48 minutes each at Norberg Mfg. Co., Milwaukee, Wis. Former time—8 hours of milling.



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Takes the place of shaping, milling and lathe work on hundreds of jobs. Makes special parts, large or small, without dies. Cuts out 40 to 60 shapes at one time by stacking the sheets one above the other.

Let's Get Together

We will send a factory trained man to your plant with a DoAll to show you what it can save for you. Just say the word.

FREE—Literature and 158-page Handbook on Contour Machining.

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Associated with the DoAll Company, Des Plaines, Ill., Manufacturers of Band Saws and Band Files for DoAll Contour Machines.

Atherton Hastings is now with the U.S.A. as a chemical engineer in charge of instrumentation.

S. B. Maurer has transferred from the materials laboratory of Wright Aeronautical Corp., Paterson, N. J., to Cleveland District, Republic Steel Corp., as an assistant research metallurgist in the research and development department.

Honored at a birthday dinner given by members of the Yale metallurgical alumni: **C. H. Mathewson**, head of the department of metallurgy at Yale University.

Henry P. George, previously instructor of metallurgy, University of Detroit, is now employed as an assistant metallurgist in the laboratory of the Frankford Arsenal.

Thomas E. Leontis has left the research and development department of the Vanadium Corp. of America and is now a graduate student in the department of metallurgy at Carnegie Institute of Technology under a Dow Chemical Co. fellowship.

Anthony Conte is now employed as a junior inspector of engineering materials in the aeronautical division of the U.S.N. and is stationed at the Curtiss-Wright airplane factories in Buffalo, N. Y.

Eric Winston is now employed at the Philadelphia Navy Yard.

Leonard D. Orr, formerly with Detroit Seamless Steel Tubes Co. as metallurgical engineer, is now an engineer in the development organization of Western Electric Co., Hawthorne Plant, Chicago.

H. M. Cluff is now production planning engineer with the Glenn L. Martin Co., Baltimore.

W. H. Gardner, formerly metallurgist, National Tube Co., Ellwood City, Pa., is now affiliated with the Navy Department as assistant metallurgist, stationed at the New York Shipbuilding Corp. at Camden, N. J.

Gerald H. Backer, formerly with the Academy of Aeronautics, is now assistant professor, College of Engineering, University of Kentucky.

John M. Scott has been made process engineer with the Remington Arms Lake City Ordnance plant, Independence, Mo.

Blake D. Mills, Jr. has left the instructing staff of Massachusetts Institute of Technology mechanical engineering department and has been ordered to active duty with the Bureau of Ordnance in the Navy Department.

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A new name in the Furnace Industry—but old in experience, as proven by the men and management back of it, and by an imposing list of outstanding installations in many prominent industrial and government plants. Your inquiry concerning VULCAN "Furnaces of Distinction" will receive prompt attention.
KEY TO ILLUSTRATIONS. 1—Radiant Tube Convection Furnace. 2—Hardening and Drawing Furnaces. 3—Continuous or Semi-Continuous Furnace. 4—Car Hearth Furnace. 5—Car Hearth Furnace. 6—Rectangular Pot Furnace. 7—Vertical H. T. Furnace.
VULCAN CORPORATION
18th & CHERRY STREETS - PHILADELPHIA, PA.
H. E. Curll, Pres. A. H. Kruger, Vice-Pres. B. G. Tarkington, Chf. Engr.

Personals

Walter L. Hodapp, formerly metallurgist, Crucible Steel Co. of America at Harrison, N. J., is now metallurgist at the Halcomb Division in Syracuse, N. Y.

J. L. Miller is now metallurgist at Firestone Tire & Rubber Co., Akron, Ohio.

J. Harry Jackson, formerly metallurgist and welding engineer, Caterpillar Tractor Co., is now research engineer, Process Metallurgy Division, Battelle Memorial Institute.

James O. Christenson, research metallurgist with the A. O. Smith Corp. of Milwaukee, has been called to active duty in the Office of the Chief of Ordnance in Washington, D. C.

Daniel E. McCarthy has been graduated from the University of Notre Dame and is now employed by the Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Columbus Floyd, formerly a member of the staff of the College of Engineering at Tulane University, is now instructor in metallurgy at the University of Detroit.

James R. Cady has resigned as instructor in metallurgy at the Colorado School of Mines to accept a position as foundry metallurgist for Columbia Steel Co. in the Pittsburg, Cal., plant.

Jack I. Medoff, physical metallurgist, has been transferred from the Harrison Works, Worthington Pump and Machinery Corp., to the Ordnance Division, Holyoke Works, Holyoke, Mass., in charge of X-ray inspection.

Ralph Hare who represents Electro Alloys Co. of Elyria, Ohio, in the New England states, will now also represent Park Chemical Co., in the same area.

J. W. Colgan, previously manager of Handy & Harman of Canada Ltd., in Toronto, is now sales manager of the parent company in New York.

H. Edward Flanders has changed his position from supervising metallurgist at the American Rolling Mill Co., Middletown, Ohio, to assistant research director with American Steel Foundries, Chicago.

Justin Blay, formerly with Inland Steel Co., is now assistant foundry metallurgist with International Harvester Co. in Indianapolis.

Eugene Caldwell, formerly general manager, Wrought Washer Mfg. Co., Milwaukee, is now general manager, Willamette Hyster Co., Portland, Ore.

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"THAT'S WHY I CALLED THE CITIES SERVICE LUBRICATION MAN IN" SAYS A. E. DAVEY, PRESIDENT OF ALLOY STEEL GEAR AND PINION COMPANY OF CHICAGO.

"I'm doing a job here that must be perfect when it leaves the shop. The people who get the gears are plenty critical." Mr. Davey says further, "I don't know everything about oil. That is why I called in the Cities Service Lubrication man. I expect him to work with my men to see that they get the oil best suited for the job."

A. E. Davey

Much work in this shop must meet rigid government inspection. All Gleason, Fellows Gear Shapers, Lee Bradner and Brown & Sharpe machines, are operated with Cities Service Lubricants. You, too, will find these high-quality fluids capable of doing the kind of work your customers want.

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Conversion Tables for Lengths

Conversion Tables for Lengths

Based on value 1 m. = 39.37 in.

From "Ready Reference Tables", by Carl Hering

In. = / Mm. = / Feet = / M. = / Yd. = / Miles = / Km. =	millimeters	inches	meters	feet	meters	yards	kilometers	miles
1	25.400 1	0.039 370	0.304 801	3.280 83	0.914 402	1.093 61	1.609 35	0.621 37
2	50.800 1	0.078 740	0.609 601	6.561 67	1.828 80	2.187 22	3.218 69	1.242 74
3	76.200 2	0.118 110	0.914 402	9.842 50	2.743 21	3.280 83	4.828 04	1.864 11
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6	152.400	0.236 220	1.828 80	19.685 0	5.486 41	6.561 67	9.656 08	3.728 22
7	177.800	0.275 590	2.133 60	22.965 8	6.400 81	7.655 28	11.265 4	4.349 59
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11	279.401	0.433 070	3.352 81	36.089 2	10.058 4	12.029 7	17.702 8	6.835 07
12	304.801	0.472 440	3.657 61	39.370 0	10.972 8	13.123 3	19.312 2	7.456 44
13	330.201	0.511 810	3.962 41	42.650 8	11.887 2	14.216 9	20.921 5	8.077 81
14	355.601	0.551 180	4.267 21	45.931 7	12.801 6	15.310 6	22.530 9	8.699 18
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17	431.801	0.669 290	5.181 61	55.774 2	15.544 8	18.591 4	27.358 9	10.563 3
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21	533.401	0.826 770	6.400 81	68.897 5	19.202 4	22.965 8	33.196 3	13.048 8
22	558.801	0.866 140	6.705 61	72.178 3	20.116 8	24.059 4	35.405 6	13.670 1
23	584.201	0.905 510	7.010 41	75.459 2	21.031 2	25.153 1	37.015 0	14.291 5
24	609.601	0.944 880	7.315 21	78.740 0	21.945 6	26.246 7	38.624 3	14.912 9
25	635.001	0.984 250	7.620 02	82.020 8	22.860 0	27.340 3	40.233 7	15.534 2
26	660.401	1.023 62	7.924 82	85.301 7	23.774 4	28.433 9	41.843 0	16.155 6
27	685.801	1.062 99	8.229 62	88.582 5	24.688 9	29.527 5	43.452 4	16.777 0
28	711.201	1.102 36	8.534 42	91.863 3	25.603 3	30.621 1	45.061 7	17.398 4
29	736.601	1.141 73	8.839 22	95.144 2	26.517 7	31.714 7	46.671 1	18.019 7
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31	787.402	1.220 47	9.448 82	101.706	28.346 5	33.901 9	49.889 8	19.262 5
32	812.802	1.259 84	9.753 62	104.987	29.260 9	34.995 6	51.499 1	19.883 8
33	838.202	1.299 21	10.058 4	108.268	30.175 3	36.089 2	53.108 5	20.505 2
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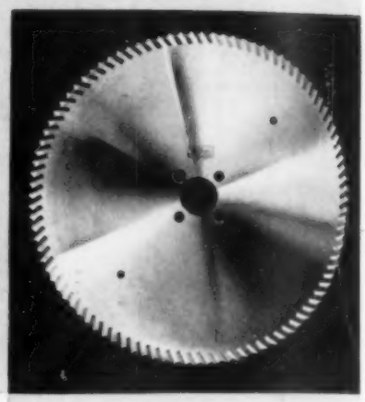
36	914.402	1.417 32	10.972 8	118.110	32.918 5	39.370 0	57.936 5	22.369 3
37	939.802	1.456 69	11.277 6	121.391	33.832 9	40.463 6	59.545 8	22.990 7
38	965.202	1.496 06	11.582 4	124.672	34.747 3	41.557 2	61.155 2	23.612 1
39	990.602	1.535 43	11.887 2	127.953	35.661 7	42.650 8	62.764 5	24.233 4
40	1 016.00	1.574 80	12.192 0	131.233	36.576 1	43.744 4	64.373 9	24.854 8
41	1 041.40	1.614 17	12.496 8	134.514	37.490 5	44.838 1	65.983 2	25.476 2
42	1 066.80	1.653 54	12.801 6	137.795	38.404 9	45.931 7	67.592 6	26.097 5
43	1 092.20	1.692 91	13.106 4	141.076	39.319 3	47.025 3	69.201 9	26.718 9
44	1 117.60	1.732 28	13.411 2	144.357	40.233 7	48.118 9	70.811 3	27.340 3
45	1 143.00	1.771 65	13.716 0	147.638	41.148 1	49.212 5	72.420 6	27.961 6
46	1 168.40	1.811 02	14.020 8	150.918	42.062 5	50.306 1	74.030 0	28.583 0
47	1 193.80	1.850 39	14.325 6	154.199	42.976 9	51.399 7	75.639 3	29.204 4
48	1 219.20	1.889 76	14.630 4	157.480	43.891 3	52.493 3	77.248 7	29.825 8
49	1 244.60	1.929 13	14.935 2	160.761	44.805 7	53.586 9	78.858 0	30.447 1
50	1 270.00	1.968 50	15.240 0	164.042	45.720 1	54.680 6	80.467 4	31.068 5

In. = / Mm. = / Feet = / M. = / Yd. = / Miles = / Km. =	millimeters	inches	meters	feet	meters	yards	kilometers	miles
51	1 295.40	2.007 87	15.544 8	167.323	46.634 5	55.774 2	82.076 7	31.689 9
52	1 320.80	2.047 24	15.849 6	170.603	47.548 9	56.867 8	83.686 1	32.311 2
53	1 346.20	2.086 61	16.154 4	173.884	48.463 3	57.961 4	85.295 4	32.932 6
54	1.371 60	2.125 98	16.459 2	177.165	49.377 7	59.055 0	86.904 7	33.554 0
55	1 397.00	2.165 35	16.764 0	180.446	50.292 1	60.148 6	88.514 1	34.175 3
56	1 422.40	2.204 72	17.068 8	183.727	51.206 5	61.242 2	90.123 4	34.796 7
57	1 447.80	2.244 09	17.373 6	187.008	52.120 9	62.335 8	91.732 8	35.418 1
58	1 473.20	2.283 46	17.678 4	190.288	53.035 3	63.429 4	93.342 1	36.039 5
59	1 498.60	2.322 83	17.983 2	193.569	53.949 7	64.523 1	94.951 5	36.660 8
60	1 524.00	2.362 20	18.288 0	196.850	54.864 1	65.616 7	96.560 8	37.282 2
61	1 549.40	2.401 57	18.592 8	200.131	55.778 5	66.710 3	98.170 2	37.903 6
62	1 574.80	2.440 94	18.897 6	203.412	56.692 9	67.803 9	99.779 5	38.524 9
63	1 600.20	2.480 31	19.202 4	206.693	57.607 3	68.897 5	101.389	39.146 3
64	1 625.60	2.519 68	19.507 2	209.973	58.521 7	69.991 1	102.998	39.767 7
65	1 651.00	2.559 05	19.812 0	213.254	59.436 1	71.084 7	104.608	40.389 0
66	1 676.40	2.598 42	20.116 8	216.535	60.350 5	72.178 3	106.217	41.010 4
67	1 701.80	2.637 79	20.421 6	219.816	61.264 9	73.271 9	107.826	41.631 8
68	1 727.20	2.677 16	20.726 4	223.097	62.179 3	74.365 6	109.436	42.253 2
69	1 752.60	2.716 53	21.031 2	226.378	63.093 7	75.459 2	111.045	42.874 5
70	1 778.00	2.755 90	21.336 0	229.658	64.008 1	76.552 8	112.654	43.495 9
71	1 803.40	2.795 27	21.640 8	232.939	64.922 5	77.646 4	114.264	44.117 3
72	1 828.80	2.834 64	21.945 6	236.220	65.836 9	78.740 0	115.873	44.738 6
73	1 854.20	2.874 01	22.250 4	239.501	66.751 3	79.833 6	117.482	45.360 0
74	1 879.60	2.913 38	22.555 2	242.782	67.665 7	80.927 2	119.092	45.981 4
75	1 905.00	2.952 75	22.860 0	246.063	68.580 1	82.020 8	120.701	46.602 7
76	1 930.40	2.992 12	23.164 8	249.343	69.494 5	83.114 4	122.310	47.224 1
77	1 955.80	3.031 49	23.469 6	252.624	70.408 9	84.208 1	123.920	47.845 5
78	1 981.20	3.070 86	23.774 4	255.905	71.323 3	85.301 7	125.529	48.466 9
79	2 006.60	3.110 23	24.079 2	259.186	72.237 7	86.395 3	127.138	49.088 2
80	2 032.00	3.149 60	24.384 0	262.467	73.152 1	87.488 9	128.748	49.709 6
81	2 057.40	3.188 97	24.688 8	265.748	74.066 5	88.582 5	130.357	50.331 0
82	2 082.80	3.228 34	24.993 6	269.028	74.981 0	89.676 1	131.966	50.952 3
83	2 108.20	3.267 71	25.298 4	272.309	75.895 4	90.769 7	133.576	51.573 7
84	2 133.60	3.307 08	25.603 3	275.590	76.809 8	91.863 3	135.185	52.195 1
85	2 159.00	3.346 45	25.908 1	278.871	77.724 2	92.956 9	136.795	52.816 4
86	2 184.40	3.385 82	26.212 9	282.152	78.638 6	94.050 6	138.404	53.437 8
87	2 209.80	3.425 19	26.517 7	285.433	79.553 0	95.144 2	140.013	54.059 2
88	2 235.20	3.464 56	26.822 5	288.713	80.467 4	96.237 8	141.623	54.680 6
89	2 260.60	3.503 93	27.127 3	291.994	81.381 8	97.331 4	143.232	55.301 9
90	2 286.00	3.543 30	27.432 1	295.275	82.296 2	98.425 0	144.841	55.923 3
91	2 311.40	3.582 67	27.736 9	298.556	83.210 6	99.518 6	146.451	56.544 7
92	2 336.80	3.622 04	28.041 7	301.837	84.125 0	100.612	148.060	57.166 0
93	2 362.20	3.661 41	28.346 5	305.118	85.039 4	101.706	149.669	57.787 4
94	2 387.60	3.700 78	28.651 3	308.398	85.953 8	102.799	151.279	58.408 8
95	2 413.00	3.740 15	28.956 1	311.679	86.868 2	103.893	152.888	59.030 1
96	2 438.40	3.779 52	29.260 9	314.960	87.782 6	104.987	154.497	59.651 5
97	2 463.80	3.818 89	29.565 7	318.241	88.697 0	106.080	156.107	60.272 9
98	2 489.20	3.858 26	29.870 5	321.522	89.611 4	107.174	157.716	60.894 3
99	2 514.60	3.897 63	30.175 3	324.803	90.525 8	108.268	159.325	61.515 6
100	2 540.01	3.937 00	30.480 1	328.083	91.440 2	109.361	160.935	62.137 0

NO WASTE *with the* MOTCH & MERRYWEATHER COLD SAWING *Combination!*



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WASTE is taboo in every quarter today . . . especially the waste of ammunition and everything that pertains thereto. Motch & Merryweather Cold Sawing Machines are cutting 1⅜" to 10½" shell steel for forging slugs with unprecedented speed, delivering clean, square ends without burr or other irregularity. Losses are practically eliminated that were running beyond bounds. Uniformity in shape and size is the rule . . . The M & M Saw Grinder and Saw Blades present every feature needed to insure fast, accurate sharpening and maximum service.

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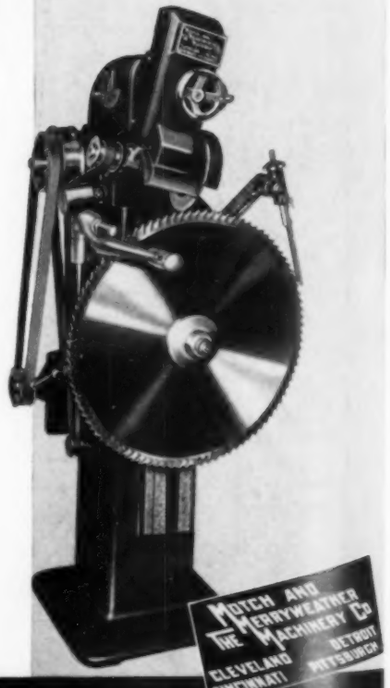

Built by **MOTCH & MERRYWEATHER**

Temperature Conversions

Albert Sauveur type of table. Look up reading in middle column; if in degrees Centigrade, read Fahrenheit equivalent in right hand column; if in degrees Fahrenheit, read Centigrade equivalent in left hand column. Values as printed in "Bethlehem Alloy Steels".

−459.4 to 0			0 to 100						100 to 1000						1000 to 2000						2000 to 3000					
C		F	C		F	C		F	C		F	C		F	C		F	C		F	C		F	C		F
−273	*−459.4*		−17.8	*0*	32	10.0	*50*	122.0	38	*100*	212	260	*500*	932	538	*1000*	1832	816	*1500*	2732	1093	*2000*	3632	1371	*2500*	4532
−268	*−450*		−17.2	*1*	33.8	10.6	*51*	123.8	43	*110*	230	266	*510*	950	543	*1010*	1850	821	*1510*	2750	1099	*2010*	3650	1377	*2510*	4550
−262	*−440*		−16.7	*2*	35.6	11.1	*52*	125.6	49	*120*	248	271	*520*	968	549	*1020*	1868	827	*1520*	2768	1104	*2020*	3668	1382	*2520*	4568
−257	*−430*		−16.1	*3*	37.4	11.7	*53*	127.4	54	*130*	266	277	*530*	986	554	*1030*	1886	832	*1530*	2786	1110	*2030*	3686	1388	*2530*	4586
−251	*−420*		−15.6	*4*	39.2	12.2	*54*	129.2	60	*140*	284	282	*540*	1004	560	*1040*	1904	838	*1540*	2804	1116	*2040*	3704	1393	*2540*	4604
−246	*−410*		−15.0	*5*	41.0	12.8	*55*	131.0	66	*150*	302	288	*550*	1022	566	*1050*	1922	843	*1550*	2822	1121	*2050*	3722	1399	*2550*	4622
−240	*−400*		−14.4	*6*	42.8	13.3	*56*	132.8	71	*160*	320	293	*560*	1040	571	*1060*	1940	849	*1560*	2840	1127	*2060*	3740	1404	*2560*	4640
−234	*−390*		−13.9	*7*	44.6	13.9	*57*	134.6	77	*170*	338	299	*570*	1058	577	*1070*	1958	854	*1570*	2858	1132	*2070*	3758	1410	*2570*	4658
−229	*−380*		−13.3	*8*	46.4	14.4	*58*	136.4	82	*180*	356	304	*580*	1076	582	*1080*	1976	860	*1580*	2876	1138	*2080*	3776	1416	*2580*	4676
−223	*−370*		−12.8	*9*	48.2	15.0	*59*	138.2	88	*190*	374	310	*590*	1094	588	*1090*	1994	866	*1590*	2894	1143	*2090*	3794	1421	*2590*	4694
−218	*−360*		−12.2	*10*	50.0	15.6	*60*	140.0	93	*200*	392	316	*600*	1112	593	*1100*	2012	871	*1600*	2912	1149	*2100*	3812	1427	*2600*	4712
−212	*−350*		−11.7	*11*	51.8	16.1	*61*	141.8	99	*210*	410	321	*610*	1130	599	*1110*	2030	877	*1610*	2930	1154	*2110*	3830	1432	*2610*	4730
−207	*−340*		−11.1	*12*	53.6	16.7	*62*	143.6	100	*212*	413.6	327	*620*	1148	604	*1120*	2048	882	*1620*	2948	1160	*2120*	3848	1438	*2620*	4748
−201	*−330*		−10.6	*13*	55.4	17.2	*63*	145.4	104	*220*	428	332	*630*	1166	610	*1130*	2066	888	*1630*	2966	1166	*2130*	3866	1443	*2630*	4766
−196	*−320*		−10.0	*14*	57.2	17.8	*64*	147.2	110	*230*	446	338	*640*	1184	616	*1140*	2084	893	*1640*	2984	1171	*2140*	3884	1449	*2640*	4784
−190	*−310*		− 9.4	*15*	59.0	18.3	*65*	149.0	116	*240*	464	343	*650*	1202	621	*1150*	2102	899	*1650*	3002	1177	*2150*	3902	1454	*2650*	4802
−184	*−300*		− 8.9	*16*	60.8	18.9	*66*	150.8	121	*250*	482	349	*660*	1220	627	*1160*	2120	904	*1660*	3020	1182	*2160*	3920	1460	*2660*	4820
−179	*−290*		− 8.3	*17*	62.6	19.4	*67*	152.6	127	*260*	500	354	*670*	1238	632	*1170*	2138	910	*1670*	3038	1188	*2170*	3938	1466	*2670*	4838
−173	*−280*		− 7.8	*18*	64.4	20.0	*68*	154.4	132	*270*	518	360	*680*	1256	638	*1180*	2156	916	*1680*	3056	1193	*2180*	3956	1471	*2680*	4856
−169	*−273*	−459.4	− 7.2	*19*	66.2	20.6	*69*	156.2	138	*280*	536	366	*690*	1274	643	*1190*	2174	921	*1690*	3074	1199	*2190*	3974	1477	*2690*	4874
−168	*−270*	−454	− 6.7	*20*	68.0	21.1	*70*	158.0	143	*290*	554	371	*700*	1292	649	*1200*	2192	927	*1700*	3092	1204	*2200*	3992	1482	*2700*	4892
−162	*−260*	−436	− 6.1	*21*	69.8	21.7	*71*	159.8	149	*300*	572	377	*710*	1310	654	*1210*	2210	932	*1710*	3110	1210	*2210*	4010	1488	*2710*	4910
−157	*−250*	−418	− 5.6	*22*	71.6	22.2	*72*	161.6	154	*310*	590	382	*720*	1328	660	*1220*	2228	938	*1720*	3128	1216	*2220*	4028	1493	*2720*	4928
−151	*−240*	−400	− 5.0	*23*	73.4	22.8	*73*	163.4	160	*320*	608	388	*730*	1346	666	*1230*	2246	943	*1730*	3146	1221	*2230*	4046	1499	*2730*	4946
−146	*−230*	−382	− 4.4	*24*	75.2	23.3	*74*	165.2	166	*330*	626	393	*740*	1364	671	*1240*	2264	949	*1740*	3164	1227	*2240*	4064	1504	*2740*	4964
−140	*−220*	−364	− 3.9	*25*	77.0	23.9	*75*	167.0	171	*340*	644	399	*750*	1382	677	*1250*	2282	954	*1750*	3182	1232	*2250*	4082	1510	*2750*	4982
−134	*−210*	−346	− 3.3	*26*	78.8	24.4	*76*	168.8	177	*350*	662	404	*760*	1400	682	*1260*	2300	960	*1760*	3200	1238	*2260*	4100	1516	*2760*	5000
−129	*−200*	−328	− 2.8	*27*	80.6	25.0	*77*	170.6	182	*360*	680	410	*770*	1418	688	*1270*	2318	966	*1770*	3218	1243	*2270*	4118	1521	*2770*	5018
−123	*−190*	−310	− 2.2	*28*	82.4	25.6	*78*	172.4	188	*370*	698	416	*780*	1436	693	*1280*	2336	971	*1780*	3236	1249	*2280*	4136	1527	*2780*	5036
−118	*−180*	−292	− 1.7	*29*	84.2	26.1	*79*	174.2	193	*380*	716	421	*790*	1454	699	*1290*	2354	977	*1790*	3254	1254	*2290*	4154	1532	*2790*	5054
−112	*−170*	−274	− 1.1	*30*	86.0	26.7	*80*	176.0	199	*390*	734	427	*800*	1472	704	*1300*	2372	982	*1800*	3272	1260	*2300*	4172	1538	*2800*	5072
−107	*−160*	−256	− 0.6	*31*	87.8	27.2	*81*	177.8	204	*400*	752	432	*810*	1490	710	*1310*	2390	988	*1810*	3290	1266	*2310*	4190	1543	*2810*	5090
−101	*−150*	−238	0.0	*32*	89.6	27.8	*82*	179.6	210	*410*	770	438	*820*	1508	716	*1320*	2408	993	*1820*	3308	1271	*2320*	4208	1549	*2820*	5108
− 96	*−140*	−220	0.6	*33*	91.4	28.3	*83*	181.4	216	*420*	788	443	*830*	1526	721	*1330*	2426	999	*1830*	3326	1277	*2330*	4226	1554	*2830*	5126
− 90	*−130*	−202	1.1	*34*	93.2	28.9	*84*	183.2	221	*430*	806	449	*840*	1544	727	*1340*	2444	1004	*1840*	3344	1282	*2340*	4244	1560	*2840*	5144
− 84	*−120*	−184	1.7	*35*	95.0	29.4	*85*	185.0	227	*440*	824	454	*850*	1562	732	*1350*	2462	1010	*1850*	3362	1288	*2350*	4262	1566	*2850*	5162
− 79	*−110*	−166	2.2	*36*	96.8	30.0	*86*	186.8	232	*450*	842	460	*860*	1580	738	*1360*	2480	1016	*1860*	3380	1293	*2360*	4280	1571	*2860*	5180
− 73	*−100*	−148	2.8	*37*	98.6	30.6	*87*	188.6	238	*460*	860	466	*870*	1598	743	*1370*	2498	1021	*1870*	3398	1299	*2370*	4298	1577	*2870*	5198
− 68	*− 90*	−130	3.3	*38*	100.4	31.1	*88*	190.4	243	*470*	878	471	*880*	1616	749	*1380*	2516	1027	*1880*	3416	1304	*2380*	4316	1582	*2880*	5216
− 62	*− 80*	−112	3.9	*39*	102.2	31.7	*89*	192.2	249	*480*	896	477	*890*	1634	754	*1390*	2534	1032	*1890*	3434	1310	*2390*	4334	1588	*2890*	5234
− 57	*− 70*	− 94	4.4	*40*	104.0	32.2	*90*	194.0	254	*490*	914	482	*900*	1652	760	*1400*	2552	1038	*1900*	3452	1316	*2400*	4352	1593	*2900*	5252
− 51	*− 60*	− 76	5.0	*41*	105.8	32.8	*91*	195.8				488	*910*	1670	766	*1410*	2570	1043	*1910*	3470	1321	*2410*	4370	1599	*2910*	5270
− 46	*− 50*	− 58	5.6	*42*	107.6	33.3	*92*	197.6				493	*920*	1688	771	*1420*	2588	1049	*1920*	3488	1327	*2420*	4388	1604	*2920*	5288
− 40	*− 40*	− 40	6.1	*43*	109.4	33.9	*93*	199.4				499	*930*	1706	777	*1430*	2606	1054	*1930*	3506	1332	*2430*	4406	1610	*2930*	5306
− 34	*− 30*	− 22	6.7	*44*	111.2	34.4	*94*	201.2				504	*940*	1724	782	*1440*	2624	1060	*1940*	3524	1338	*2440*	4424	1616	*2940*	5324
− 29	*− 20*	− 4	7.2	*45*	113.0	35.0	*95*	203.0				510	*950*	1742	788	*1450*	2642	1066	*1950*	3542	1343	*2450*	4442	1621	*2950*	5342
− 23	*− 10*	14	7.8	*46*	114.8	35.6	*96*	204.8				516	*960*	1760	793	*1460*	2660	1071	*1960*	3560	1349	*2460*	4460	1627	*2960*	5360
− 17.8	*0*	32	8.3	*47*	116.6	36.1	*97*	206.6				521	*970*	1778	799	*1470*	2678	1077	*1970*	3578	1354	*2470*	4478	1632	*2970*	5378
			8.9	*48*	118.4	36.7	*98*	208.4				527	*980*	1796	804	*1480*	2696	1082	*1980*	3596	1360	*2480*	4496	1638	*2980*	5396
			9.4	*49*	120.2	37.2	*99*	210.2				532	*990*	1814	810	*1490*	2714	1088	*1990*	3614	1366	*2490*	4514	1643	*2990*	5414
						37.8	*100*	212.0				538	*1000*	1832				1093	*2000*	3632				1649	*3000*	5432

Select your brushes by pencil and paper

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Early in 1941 the Washington Chapter ⊜ instituted an annual lecture in memory of George K. Burgess, past director of the National Bureau of Standards. The lecturer was Paul D. Merica, an early associate at the Bureau, and the stimulating text is printed here

The Art of Alloy Engineering

LET US TURN to a general examination of the industry of alloys and review for a few moments some of the simpler and yet fundamental aspects of this industry and of the art of alloy metallurgy. I wish to consider the term "alloy" broadly, including ferrous as well as non-ferrous materials.

At the outset, it should be emphasized that in this industry of alloys we are really engaged in the development, production, and delivery to the engineering industries of *engineering properties*. Those properties that we do so produce and deliver happen to be attached to metals and alloys, but it is their properties and their engineering performance which engineers and industry buy and employ usefully; the alloys are merely their carriers. Our fundamental business as alloy engineers is, therefore, first to devise those alloy combinations that will yield the characteristics we need, and then to fabricate their carrier alloys into the forms required for their industrial utilization. I want to speak briefly about both of these major components of the job of alloy metallurgy.

First, about fabrication:

Even a casual scrutiny of the subject will persuade us that the art of alloys fabrication is today in a state of most active development — more active perhaps than at any time in the past. I venture the assertion that it is in the field of fabrication that alloy metallurgy is making its most rapid progress today.

When such items as the following are cited, they are only matters of common knowledge: *Continuous rolling* of steel sheets, supplanting the older and laborious hand and pack rolling; the rapid development of the *art of welding* of steels and the alloys to replace riveting, and involving such ingenious methods as "shot-welding"; *hot extrusion* of tubes and irregular sections, particularly in difficultly forgeable steels and alloys; the rapidly growing use of the *electric furnace* with its better metallurgical control; the onward march of production casting in *permanent molds;* and many others.

There are other developments in this category which are newer and perhaps less well known. There is no doubt that the art of *continuous casting* of metals, now in its very infancy, is moving ahead. I mean, of course, the continuous production from molten metal of semi-finished shapes, by solidification in molds, dies, or rolls. Processes of various types for the *extrusion casting* of billets and rods are almost certainly coming into production within the near future. By these processes we produce a continuous metal billet rather than a series of

By Paul D. Merica
Vice-President
The International Nickel Co., Inc.
New York City

ingots, and the billet is continuously solidifying in the mold and being removed from it. It is not difficult to appreciate the advantages which accrue to a casting method that avoids the necessity of scrap loss through ingot topping, and also affords greater certainty of sound internal structure in metal billets.

In the HAZELETT process of direct rolling, direct production from molten metal is carried even further, and sheet or strip metal is directly and continuously rolled from a molten bath. This process, although still in the development stage for higher melting point alloys, has been operated commercially on lead, brass, and aluminum; on a new type of HAZELETT mill, production speeds as high as 500 ft. per min. have been attained, rolling metal directly from the molten condition to gages as thin as 0.02 in.

There is today a slow but definite trend of encroachment of the *electroplating* or *electroforming* technique of fabrication upon the fields of other methods. Very thin, electroformed copper sheets are on the market today for roofing and other purposes. Electrodeposited tin as well as zinc, marketed as deposited or after diffusion by heat treatment, are being commercially applied to steel in substitution for the older dipped coatings. A most interesting development of this nature is the production of fine metal screen by electroplating. The screen pattern is applied to a master plate by processes similar to those of photo-engraving, following which this plate is placed on a plating drum and the screen is plated and unwound off the drum continuously. Any sort of pattern can be produced by this method and in continuous strips or sheets. It will be observed that the electroforming method of fabrication is ideally suited to the low cost production of thin sections and complicated patterns — just the sections and forms which, by other methods of fabrication, are expensive to produce. I think there is no doubt that we are only on the threshold of more general expansion of the use of the electroforming art.

Although the art of pressure die casting is not a new one, it must receive prominent mention in any roll call of fabrication developments, not only by reason of the extent to which die castings are moving ahead and replacing articles formed of other metals by more expensive fabrication operations, but also in tribute to the metallurgical feat of having worked out a cheap method for the production of articles of complicated shape, cast directly to a dimension tolerance of 0.001 to 0.002 in. and which require practically no machining, and which finally have good mechanical properties, with tensile strengths as high as 40,000 psi. Pressure die casting in other metals such as iron and brass, although not yet practiced, is probably to be realized when improved materials are available for the dies.

"Manipulation" of Alloy Properties

Leaving the subject of fabrication, I should like to tackle the question of our position *vis-a-vis* the more fundamental part of the alloy engineering job — that of devising or building alloys to the diverse demands of present day engineering. How well can we today "manipulate" and control properties, and how wide and diverse an assortment of alloy properties do we today make available to industry?

Obviously, our powers in this direction vary considerably in the different fields of alloy application.

We must, first of all, admit that there are several industrially valuable characteristics of alloys which are very unresponsive to our control or command; we are obliged to accept them more or less as we find them in the metallic elements themselves. Good examples are density and rigidity. These two properties are stubbornly unalterable characteristics of the individual metals, and are relatively insensible to modulation through alloying art. We are fortunate in having at our disposal industrial alloys throughout a wide range of both densities and rigidities, but the art of alloying cannot be said to have made great contribution to this happy situation.

Most of the useful engineering properties and characteristics of alloys are what might be called partially responsive to manipulation; they may be found in useful intensity only in a few metals or alloys, or — although inherent in many alloys — may be susceptible of only limited alteration and response to manipulation.

High values of *electrical and thermal conductivity* are found only in a few metals, notably copper, aluminum, and silver. These cannot be improved by alloying — they are indeed always impaired by alloying. We do our job best, in offering these properties to industry, when we offer the pure and naked metals, as it were, unsullied by the touch of the alloying art! The reciprocals of these properties however — electrical and thermal resistivity — are more

responsive to alloying, and we are able to run a wide gamut in ductile and fabricable alloys, from metals having the low electrical resistivity of copper, to alloys of very high resistivity, such as the chromium-nickel alloys for electrical resistors and heating elements.

Magnetic properties of alloys, although attributable to the inherent ferro-magnetism of a few metals only, have in recent years shown themselves amenable to a considerable degree of control, both in the field of high permeability and in that of high magnetic retentivity. We have been able to step up from the maximum permeability of commercial silicon-iron, about 6000 times that of air, to that of permalloy, which from 100,000 and even 300,000 has recently been pushed up, at least in laboratory specimens, to as high as 500,000. In the modern Alnico and Mishima magnet steels, it has been possible to improve the quality of permanent magnetism as much as five-fold. In this field of magnetic alloys the art of the physicist and metallurgist has been as strikingly employed in "stepping-up" the performance of alloys as anywhere in the whole field of alloy metallurgy. We are beginning to understand some of the principles which must be followed in pushing forward the performance, both of magnetically soft and of magnetically hard materials. There is a science of magnetic alloys in the making.

Corrosion resistance of alloys is moderately "responsive" to control. This is a property which has very generously engaged the time and effort of metallurgists and chemists. In attempting to mitigate the corrodibility of metals or alloys, we start with a big handicap, since the chemical reactivity of elements is a fairly fundamental and unalterable characteristic, possibly having to do with the number of electrons in the outer regions of the atomic volume — that is to say, a function associated with the very architecture of the atom. Our effort in manipulating corrosion resistance, particularly in steel and iron alloys, is therefore that of restraining rather than of building up an inherent quality.

Now, in this effort we are aided by some fortunate intervening circumstances — particularly the possibility of forming a self-healing, protective film, well recognized, for example, in the retardation of corrosion in aluminum. Probably the most spectacular use of protective film-forming constituents in building up the corrosion resistance of alloys is in the stainless steels, in which, by the use of chromium, readily rusting steels are converted into practically rust-proof ones.

With such an impressive example of corrosion retardation before us, amounting in this case substantially to corrosion suppression, we are apt to overlook more modest but important and numerous examples of the application of this art in other directions.

One of the earliest examples was that of the conscious use of small amounts of copper in steel, as little as 0.25%, which in atmospheric exposure serve to build up its corrosion resistance by as much as 100 to 200%, as measured by service tests. More recently it has been shown that small amounts of copper and nickel may retard the corrosion of steel and extend its service life by as much as 500%. The addition of 2 or 3% of molybdenum to stainless steel confers a further improvement of corrosion resistance, particularly in environments containing salt water, chlorides, or sulphites.

In the non-ferrous field may be cited the use of about 2% of aluminum in brass, particularly in condenser tubes and for marine exposures, this comparatively small amount, of an element forming an oxide film, conferring substantial improvement on the corrosion resistance of the brass, amounting under some conditions to as much as 300%. Just recently, an arsenical copper has been announced by one of the leading copper mills, carrying about 0.5% of arsenic, for the improvement of the film-forming characteristics of the copper.

And finally an amusing example is the demonstrated effect of less than 1% of iron in improving the corrosion resistance of cupro-nickel alloys, particularly in salt water. Here, surprisingly enough, we use a readily corrodible metal for the purpose of further improving the corrosion resistance of much more corrosion resistant metals!

It is evident that a technique of corrosion protection is in the making, through the "doctoring" of alloys with "film-forming" elements. And I should like to emphasize that the amounts of film-forming constituent which yield important advantage are quite small, and insufficient generally to modify unduly the other useful properties of the material. In some cases, of course, they may happen actually to improve these as well. This is most important from the standpoint of alloy-building technique, in which we are anxious to be able to adjust and modify individual alloy properties without affecting others.

When now we consider that we are probably only at the beginning of our unfolding knowledge of the complicated nature of film formation and effect, as well as of those other factors retarding corrosion which we recognize as inherent in some metals, one is not over-optimistic in anticipating that we shall in the future make much more effective use of film-forming alloy constituents, and go much further in the development of corrosion resistant steels and alloys generally.

We have had glimpses of the possibility of initiating growth of alloy films in one environment, which may thereafter be very effective in some other environment; for instance, oxide films on copper give protection against tarnish in sulphur-bearing atmospheres. I would consider it very probable that we are far from having exhausted the interesting possibilities that may be discovered through their exploration.

And we are getting hints of other techniques, as well, by which we may retard the corrosion of alloys even more. Here is an intriguing possibility! We are accustomed to the view that it is preferable from the standpoint of its resistance to galvanic corrosion that an alloy should be homogeneous in structure, and that view is fully justified as long as the heterogeneity has random distribution. But if the two heterogeneous components of a sheet or tube wall, for example, are in the form of alternate complete layers — that is another story, as WESLEY has demonstrated in his multi-layered steel plate. This consists of alternate layers of plain steel and of alloyed steel, and it proves to be particularly resistant to the pitting type of corrosion, since any freshly forming pits constantly run into the effective galvanic barriers of the alloy layers.

Mechanical Properties respond well to manipulation. Passing on in our survey, there is a group of very important engineering properties quite responsive to our molding, and over which, particularly in recent years, we have been able to gain a quite impressive measure of control. These are the mechanical properties, represented by strength and hardness. It is fortunate, incidentally, that these happen to be the very properties by reason of which metals on the whole derive their industrial value.

Mankind was very lucky in having had thrust into his hands, very early, about the cheapest material, of high hardness and strength, that he could use. Perhaps it was for this very reason that the art of hardening *other* alloys was so long in appearing and developing.

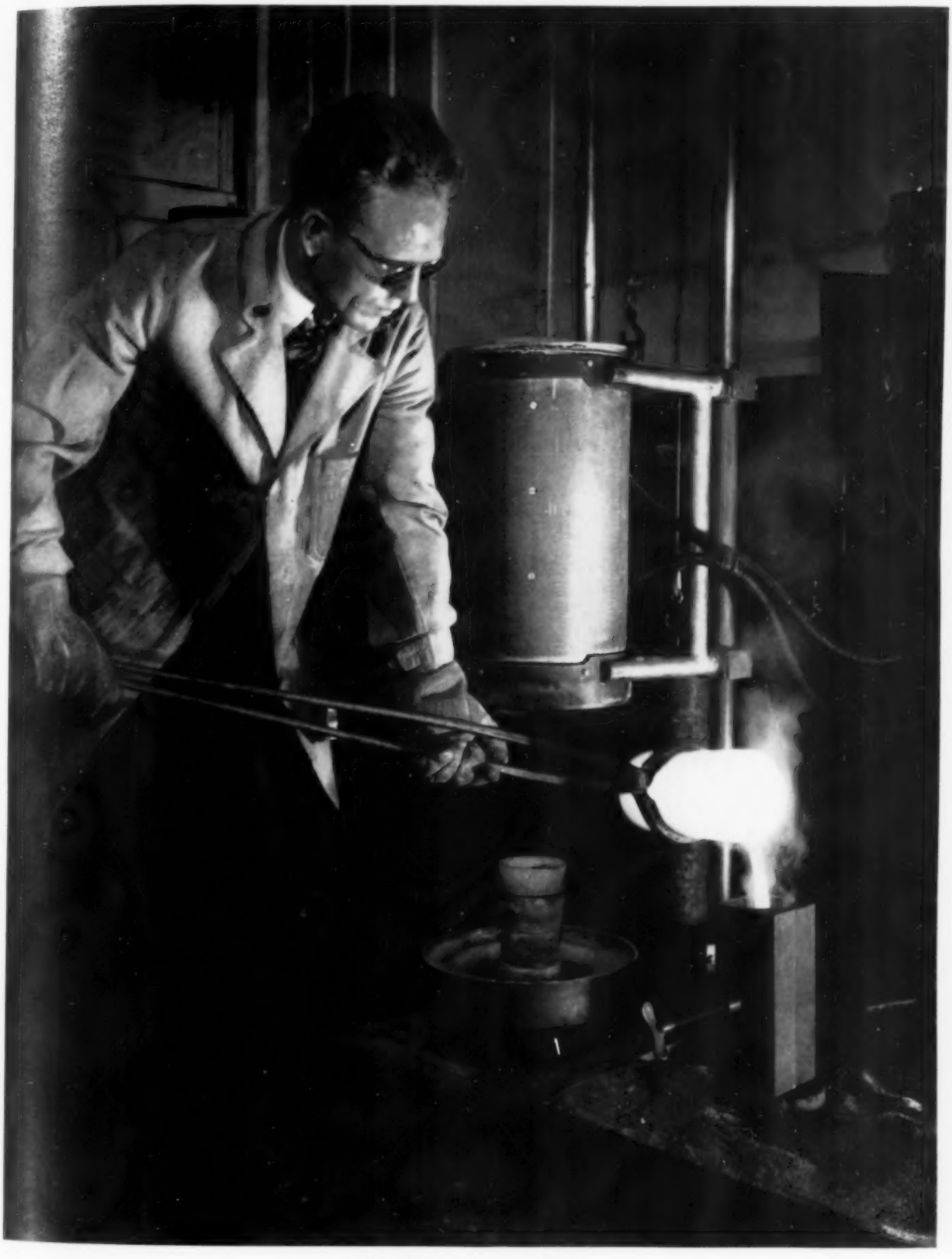
However, this general art did finally put in an appearance (initially in the form of WILM's age hardening duralumin), and within the past 20 years this now well-known art of "age hardening" has been very rapidly developed. I want only to recall to you two facts about it which are important from the standpoint of alloy engineering: First, the fundamental principles underlying this art are reasonably well understood, and second, the art appears to be generally applicable to *all* metals and alloys at will. Here, therefore, is an art where by suitable alloying and heat treatment we may enhance the mechanical properties of practically all metallic materials at will.

And the degree of enhancement of these properties is considerable; the strength of a soft metal such as aluminum being increased from about 15,000 psi. to over 60,000 psi. in age hardened duralumin, and that of copper, nickel, gold, and silver alloys being raised from two-fold to as much as five-fold the strength of the base alloys and into strength ranges of 150,000 to 175,000 psi.

Thus, in addition to our ability to produce and deliver alloy steels having tensile strengths at the 300,000-psi. level and over, we are able to bring the strength levels of many non-ferrous alloys up practically to 200,000 psi., a good level even for steel!

Now here again, as in the case of corrosion resistance, the important fact which I wish to emphasize, is that these enhancements of mechanical properties may usually be secured by relatively modest alterations of alloy composition — by additions in such small quantity as not to alter or disturb substantially the other useful properties of the alloys. Duralumin contains only about 5% of alloying elements which raise the density of the aluminum only about 5% and leave most of its other properties unaltered. This is an ideal type of art in alloy engineering — the development of a science and method for manipulation of alloys which permits flexible control of individual alloy properties over wide ranges and without undue modification of other properties.

I should like to digress a moment at this point to comment on a situation in the field of age hardening alloys which has some illuminating aspects. With the exception of the "old trouper" in this field, duralumin, and a very few others, these alloys are not yet used in great volume by industry, in spite of what appear to

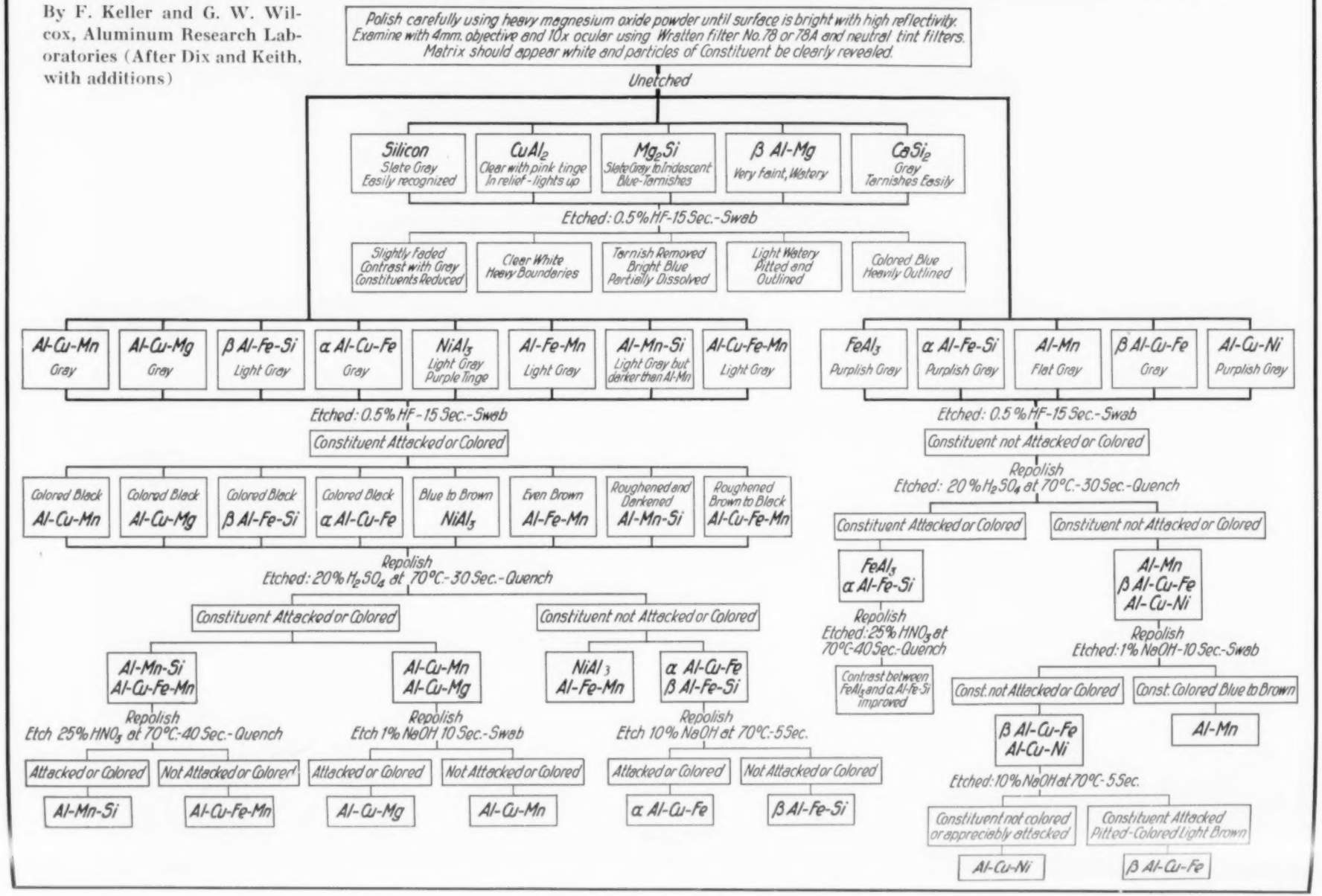


The Birth of an Alloy

J. M. Kelly pours a small ingot in the Westinghouse Laboratories of a hard copper-iron-cobalt alloy

Identification of Constituents in Commercial Aluminum Alloys

By F. Keller and G. W. Wilcox, Aluminum Research Laboratories (After Dix and Keith, with additions)



Metal Progress: 1941 Reference Issue, Page 430

be most attractive mechanical properties. Here is a case in which, reversing the conventional roles, engineering industry has lagged behind metallurgy and has not yet begun to take full advantage of new and improved alloy products. Why is this true?

Of course it arises from many reasons, of which certainly one is inertia. It always requires more time than we think for improvements, even important ones, to be absorbed into industrial practice, particularly when they require important design changes in order to render them economically useful.

But it arises in part also from the fact that age hardening alloys often have troublesome disabilities, such as susceptibility to embrittlement, low fatigue strength ratio, and certain difficulties in fabrication. I mention this aspect of the situation as an illustration of what appears to be a general truth in alloy metallurgy. Whenever we manage, by research and invention, to push upward the properties or performance of our alloy materials, we find that the steps by which this had been accomplished bring along also some unexpected and often most unwelcome impairments of other properties, sometimes not readily apparent, with which we then have to deal. Sometimes indeed, in our more discouraged moments, we are likely to think that disabilities grow more rapidly in alloys than do virtues! In any event — as is well known to all in the profession — the business of wrestling with the disabilities of alloys absorbs a good deal of the time and effort of alloy metallurgists, and often the major technical effort involved in bringing out new alloy material may be that of overcoming those disabilities which appear always to accompany major improvements.

Hardness is a very responsive property. This characteristic, associated as it is with resistance to mechanical wear and abrasion, is hardly less valuable in steels, irons, and alloys than that of mechanical strength. Through the newer art of precipitation hardening, which I have just mentioned, we are today able to bring about in most alloy combinations not only strength enhancement, but also hardness enhancement, amounting often to as much as 100 to 200%. This ability permits us to build up the Brinell hardness of many non-ferrous alloys to values as high as 300 or 400, even 500.

In addition we have, in other materials and by other methods, been able to push our hardness level in alloys very much higher. Thus, in certain alloy cast irons, we are able through manipulation of composition and structure to secure surface hardness values of 750 to 900 Brinell. Through the process of nitride hardening, thin surface layers are produced in steel having Brinell hardness values up around 1000. I cite also the development within the past several years of the newer carbide tool materials, in which combinations of hard tungsten and other carbides are compacted to produce tools of performance far out-distancing, in important respects, even the high speed steels.

Many very interesting and impressive stories can be told today of the economic contribution which modern alloys of high hardness and abrasion resistance have made in permitting grinding, crushing, machining, and other operations at lower costs and higher efficiency, where enhancement of performance, amounting to from 200 to 500% is not at all uncommon, as compared with the competitive materials in prior use. It would be interesting to compute, for example, the per-pound value of some of the sintered carbide tool alloys, on the basis of crediting them with the economic value of the machining economies effected through their use, as compared with the use of their nearest competitors!

Multiplex Properties Are Demanded

The foregoing discussion has been concerned with the production and control of simple and single alloy properties, and it seems clear that many of these properties are today reasonably subject to control and modulation in industrial alloys, and that most of them are commercially available in values covering a fairly broad range. It is, however, possible that we are approaching the limiting or maximum values attainable in many of these simple properties, although I realize that there is no surer manner of disproving one's intelligence than to attempt to forecast that something of a technologic character will *not* happen in the future!

But I could not be too confident, for example, that we can ever get much more in the way of tensile strength out of steel than the 300,000 psi. or so now available, nor more in the way of electrical conductivity than that of copper or silver. In the nitrided cases on steel, we have surely extended our level of attainable hardness pretty far.

It is not, however, single properties alone which are usually demanded in commercial

Standards for Estimating Grain Size (Non-Ferrous)

American Society for Testing Materials Standard E2-39T (copyrighted) for annealed materials such as brass, bronze, nickel silver
Actual diameter of average grain is noted; Magnification of micros: 75 ×

0.010 mm. 0.025 mm. 0.045 mm. 0.090 mm. 0.150 mm.

0.015 mm. 0.035 mm. 0.065 mm. 0.120 mm. 0.200 mm.

alloys today. The engineer is not satisfied merely with high tensile strength, but usually demands other accompanying properties, often of a nature not readily reconcilable with high strength. Thus an automotive gear forging must have high strength and high resistance to surface wear, but also acceptable machinability and absence of fragility. Electrical transmission cable requires a material of high electrical conductivity, but also high mechanical strength and ready fabricability.

Indeed, alloy properties are almost always demanded in what might be called "multiplex" combinations, and that simple fact vastly complicates the art of alloy metallurgy. It is the supplying of those multiplex and complex combinations that creates most of our "metallurgical headaches". It is this fact also that leads to that impressive diversity of alloy products which awes the statistician and is the despair of the alloy producer. It is claimed that there are well over 5000 different alloys and steels in commercial use today. The steel industry alone is said to produce and sell some 100,000 different items. In a really tiny portion of the alloy field — that of dental gold alloys used for dentures and bridges — there are said to be 150 commercial alloys offered today!

What are the reasons for this perplexing diversity of metallic products? Certainly it arises partly in consequence of the admittedly complex and variegated demands of the consuming industries. But it arises also, and in fairly generous measure, from the necessity imposed upon the alloy industry by the pressure of these demands, namely, to extract the very utmost in performance value from its available materials. And the art of alloy metallurgy, faced with the self-conflicting demands of engineers for "property combinations", meets it by offering a very numerous series of "compromises" in alloy character and performance.

Perhaps a simple illustration will make my meaning clearer. Engineers would like gray cast iron for structural purposes of as high strength as possible — 50,000 psi., 100,000 psi., whatever the foundries could offer. And it isn't too difficult to produce iron of strength exceeding 50,000 psi. But as the composition and character of the iron are changed in such manner as to yield these higher strength values, something else also happens. The iron becomes progressively less machinable, and this is a consideration of almost equal importance to the engineer as is higher strength.

So the engineer and the foundryman are obliged to compromise on a particular composition of iron that will have the maximum strength together with adequate machinability for the particular job. But the machinability of iron castings depends upon the casting section and design, so that the compromise solution, so arrived at, may vary considerably with the design problem with which the engineer is dealing. In order to extract from gray iron its maximum potentialities and value, it is therefore necessary to produce it in a variety of compositions and qualities, suited for particular situations and service.

A considerable portion of the time and attention of alloy metallurgists is currently devoted to the job of seeking or of producing materials which might thus be called "compromise" materials, since they are so chosen as to possess the maximum engineering performance with the least attendant amount of disability — the disability usually being related to fabricability or sometimes fragility. And in spite of the excellent organized effort which is proceeding always in the direction of standardization of metallic materials, the pressure of engineering demand is still so great as to force the alloy industry to diversify its products more rapidly than they can usefully be stabilized and standardized.

Now it seems to me that precisely in this field of seeking and developing better "compromise combinations" of alloy properties, or "sets of improved properties", lies the greatest opportunity for alloy metallurgy. I believe it is possible to visualize many directions in which further progress may be possible in this sense.

Whither Are We Headed in Alloys?

Let us review some of these possible directions of further progress.

One of the most common components of industrially useful property combinations is one or more of the "fabricability" attributes, such as machinability, weldability, and ductility. Most of these attributes are moderately responsive characteristics, and in the double sense that by appropriate modification of the fabricating technique, as well as of the alloy characteristics, it is usually possible to bring about considerable enhancement of its amenability to fabrication.

Machinability, for example, is notoriously a characteristic over which we have recently been able to achieve a considerable measure of

control — not of course as much as we should like, but a very respectable degree of control nevertheless.

Both in steels and in alloys, we are today generally able to bring about enhancement of machinability through alloying additions such as sulphur, lead, and selenium, which break up the structure and embrittle the chip cut by the machine tool. The degree of improvement, as reflected in machining production, may amount to as much as 50 to 100%. It is gratifying to realize that we can practically universally command improvements of this order by a suitable and small alloying addition which does not unduly impair the other useful properties of the materials.

Similar stories can be told of other fabricability characteristics, so one is not too bold in believing that we shall do much more in the future in improving the fabricability components of "industrial property sets", and hence of raising the level of our utilizable primary alloy properties.

On the other side of the picture, I consider it also probable that a major direction in which such improvements may be made available is through progress in the arts of fabricating alloys.

I have commented on the extraordinary activity in the development of the art of metals fabrication — an art which I expect to develop continually, perhaps even in intensified tempo. Now quite apart from the direct economic value of improvements in fabrication technique, they often yield an equal, perhaps at times even greater, indirect value in their contribution to the art of making better engineering properties available in fabricable alloys.

The development of the art of grinding, in partial replacement of machining, opened the industrial door to hard varieties of both steel and cast iron for many applications which had been closed to them before, for the simple reason that they were too hard to be machined. A good example is the cast iron automobile camshaft of today, with its chilled cam surfaces finished by grinding instead of by machining as in the past. And the improvement of the machining art itself, through the use of newer types of cutting tools and otherwise, has permitted the effective use of steels and other alloy materials at higher machinable levels of mechanical properties.

Sometimes the development of a new fabrication art not only permits, but even requires, the use of better alloy materials. A good example is the art of welding. In the days when steel structures were assembled by riveting, it was current dogma that alloy steels could not economically be used in competition with carbon steels, since the latter, strengthened with some 0.30 to 0.40% carbon, yielded what were considered to be adequate mechanical properties. With the advent of welding of steel structures, however, steels are needed which tolerate better the rather drastic thermal operation, without the undue hardening and embrittlement experienced in steels containing so much carbon. Lower carbon steels, with carbon from 0.10 to 0.25%, together with a moderate alloy content to give the required strength, meet the new situation created by the advance of the welding art, and it seems clear that a new field for alloy steels is about to be opened up in welded steel structures. These steels offer better "compromise" properties of strength and fabricability also in other directions as, for example, in forming and drawing.

It is thus a fact of general significance in the alloy business that major changes in engineering technique in any field have great influence upon the trend of development in alloy materials. In the field of zinc-base die castings, the development of a new fabrication art opened an opportunity in a totally new direction for zinc alloys — a field which hitherto had been filled by electroplated steel or iron, and by brass.

Powder Metallurgy Offers Much Promise

The new art of powder metallurgy offers a further example of the influence of a new art of alloy fabrication on the level of useful properties attainable in alloys, inasmuch as it affords the possibility of producing useful alloy mixtures which would be impossible of production by conventional means. Thus by the powder method we produce the well-known oil-less bearing, a mixture of graphite and copper which is impossible by fusion mixing, since the graphite will obstinately float on top of liquid copper. And similarly the alloy of copper and tungsten for electrical contacts can be powder-mixed and compacted, but is impossible to alloy by fusion since tungsten and copper are practically insoluble in each other.

We have in the past been restricted to the list of alloys which form homogeneous solutions in the liquid state, and we realize today that that simple and now unnecessary restriction

has deprived us of some really valuable industrial alloys.

Using powders, we are not even restricted to metallic components. One of the most interesting and provocative "powder alloys", to me, is the "alloy" of steel and diamonds used as a cutting disk or as a boring drill, and which offers considerable promise for difficult cutting and drilling operations.

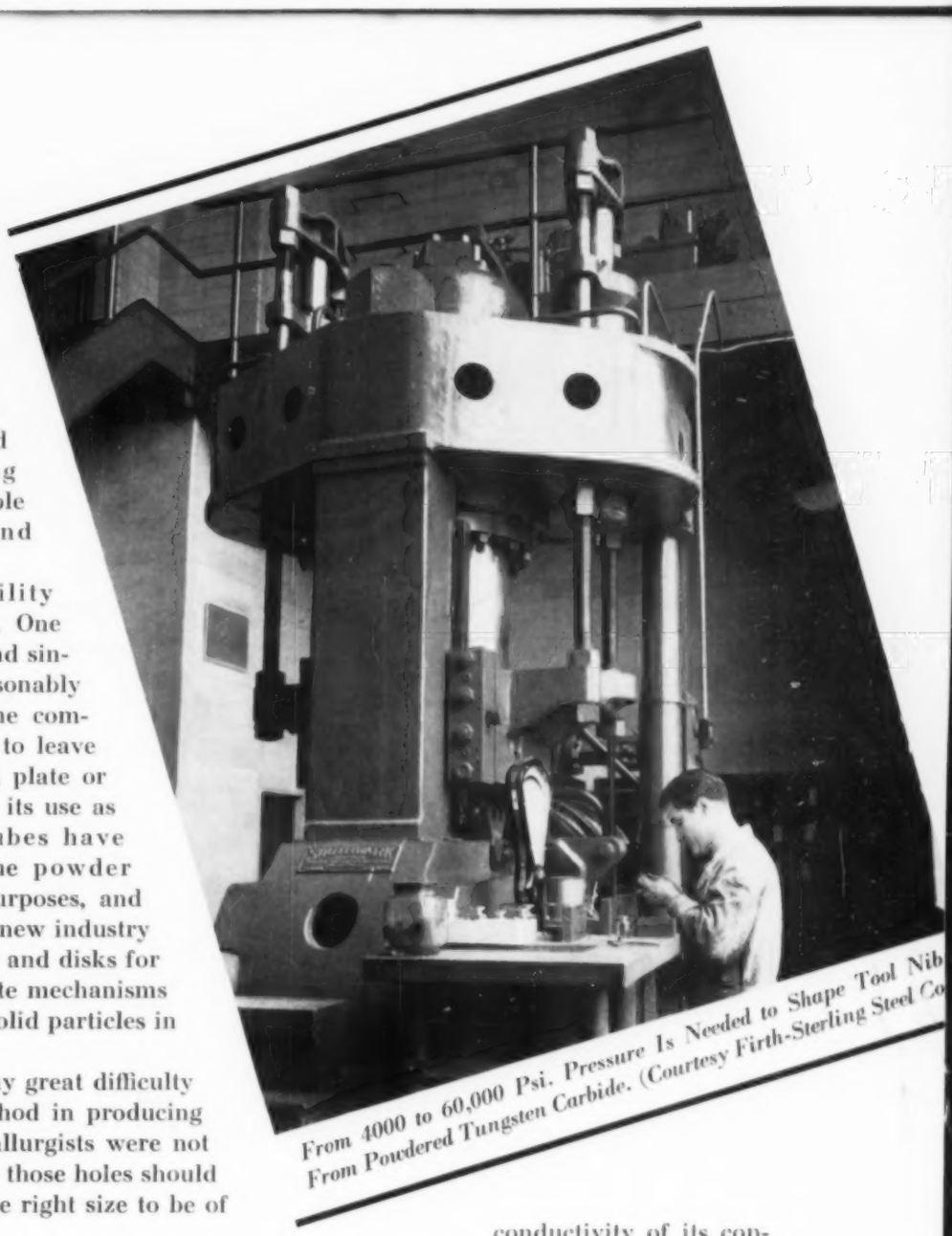
And here is another possibility opened up by powder metallurgy. One can so regulate the compacting and sintering operation as to control reasonably well the resultant porosity of the compacted article, and in particular to leave such a distribution of voids in a plate or tube, for example, as will permit its use as a filter. Porous nickel filter tubes have actually been produced by the powder method and used for filtering purposes, and one of the important firms in the new industry produces a whole line of thimbles and disks for protecting gas engines and delicate mechanisms from being fouled by occasional solid particles in the liquids or gases fed to them.

There never was of course any great difficulty by the old and conventional method in producing holes in alloy castings! But metallurgists were not usually in position to arrange that those holes should be in just the right spot and of the right size to be of commercial value!

Obviously the new powder-alloying technique has helped, and will probably help much more, to lift considerably the horizon of our alloy possibilites and capabilities.

"Localized" Properties — We have seen that the alloy metallurgist's constant struggle is to secure in his materials the properties, desired or specified, without impairing unduly their other useful properties — a struggle in which he must often make practical compromises between incompatible properties.

There is a steady growth of a group of somewhat diverse techniques for the attainment of these compromise objectives, which operate by localizing in different parts of the fabricated metallic article the conflicting sets of properties, usually two. One technique of this sort is the production of the so-called bi-metals or clad metals, of which there are now a good many operating processes for the manufacture of numerous commercial substances in plate, strip or wire form. Copper-clad steel conserves the electrical



From 4000 to 60,000 Psi. Pressure Is Needed to Shape Tool Nib From Powdered Tungsten Carbide. (Courtesy Firth-Sterling Steel Co.

conductivity of its copper portion, while availing itself of the high tensile strength of the steel core. A number of corrosion resistant clad materials are on the market, such as nickel-clad steel and stainless-clad steel, and in the jewelry field we find the various so-called "filled" materials, in which the compromise effected is very simply that of corrosion resistance and appearance at minimum cost. In the field of abrasion resistant articles, we encounter steel "weld-clad" with Stellite, and with hard alloy iron effecting a compromise between hardness of the surface material and mechanical strength and toughness of the core. Babbitt and other "anti-friction alloys" are cast on steel strip in a continuous manner, and form the raw material for a multitude of steel-backed, thin-wall machine bearings.

MAGNESIUM ALLOYS

Compositions, Properties, and Designations of American Commercial Alloys

Compiled by H.S. Jerabek, University of Minnesota, W.H. Gross of Dow Chemical Co., and R.T. Wood of American Magnesium Corp.

Form	A.S.T.M. Alloy No.	A.S.T.M. Specification No.	Navy Bureau of Aeronautics Alloy No.	Navy Bureau of Aeronautics Specification No.	U.S. Army Air Corps Grade	U.S. Army Air Corps Specification No.	S.A.E. No.	AMS(j)	Am. Mg. Corp.	Dow Chem. Co.	Composition, Per Cent Magnesium=Remainder Al	Mn	Zn	Condition	Tensile Strength (a) Typical	Tensile Strength (a) Min.	Yield Strength (a) Typical	Yield Strength (a) Min.	Elongation in 2 in.,% Typical	Elongation in 2 in.,% Min.	Brinell Hardness	Shear Strength (a)	Endurance (b)	Uses and Characteristics
Sand Castings	4	B80-41T	4	M-112h	2	52-74-1C	50	4420	265	H	6.0	0.2	3.0	As Cast	27	24	11	10	5	4	51	17	10	General casting use.
					1			4422						Cast; Soln. T. (c)	37	30	12	10	10	6	53	18	10	Sand and permanent mold castings.
					1			4424						Cast; Soln. T.; Aged (d)	37	32	18	16	4	2	70	19	9	
									241		8.0	0.1		Cast; Soln. T	33	29	11	9	10	6	48	18	7.5	Sand and permanent mold castings.
	12	B80-41T	12	M-112h			500		260	C	9.0	0.1	2.0	As Cast	23	20	14	10	1		62	18	10	Pressure tight castings.
														Cast; Soln. T. (c)	39	30	14	10	10	6	61	20	10	
								4434						Cast; Soln. T.; Aged (d)	38	32	20	18	3	1	77	22	10	
	2	B80-41T							240	G	10.0	0.1		As Cast	21	18	12	10	2	1	53	18	8	Sand and permanent mold castings.
														Cast; Soln. T.; (c)	33	29	12	10	8	5	52	20	10	
														Cast; Soln. T.; Aged (d)	34	29	19	17	1		69	22	8	
	3	B80-41T							246	B	12.0	0.1		-"- -"- -"-	32	27	20	17	0.5		85	19	7	Hard castings. Pistons.
	11	B80-41T	11	M-112h	2	52-74-1C			403	M		1.5		As Cast	14	12	4		5	3	33	11		Best salt water resistance.
									244		4.0	0.3		-"- -"-	24	20	9	8	6	4	44	14		Aircraft tank fittings.
Die Castings	12	B94-39T		M-369-2	1	11319			230	K	10.0	0.1	(f)	As Cast	30		22		1		68			Thin section die castings.
	13	B94-39T		M-369-2	1	11319	501	4490	263	R	9.0	0.2	0.6	-"- -"-	33		20		3		66			General die castings.
Extruded Bars and Rods	6	B107-41T							53s	F	4.0	0.3		As Extruded	40	37	29	25	16	12	47		14	General extrusions.
	8	B107-41T	8	M-314c(e)	1	11320(e)		4350A	57s	J	6.5	0.2	0.7	-"- -"- (g)	43	40	30	26	17	12	54		17	Improved strength.
	8	B107-41T	8	M-314c(e)	1	11320(e)	520		57s	J	6.5	0.2	0.7	-"- -"- ; Stretched	44	40	32	26	15	12	55	20	15	Screw machine rod.
	11	B107-41T	11	M-314c	2	11320			3s	M		1.5		-"- -"-	42	32	27	20	8	5	42		10	Best salt water resistance.
	9	B107-41T							58s	O	8.5	0.2	0.5	-"- -"-	47	43	33	28	11	9	61		17	Bars of high strength.
	15	B107-41T	15	M-314c(e)	1	11320(e)	521		74s	X	3.0	0.2	3.0	-"- -"-	42	39	30	26	19	15	51		18	Heat treatable bar.
	15a	B107-41T	15a	M-314c(e)	1	11320(e)	521		74s	X				-"- -"- ; Aged	44	41	34	30	13	10	54		17	
									59s	G	10.0	0.1		-"- -"- ; Stretched	51	45	38	33	9	6	70	23	16	Highest hardness and strength.
	18	B107-41T					52		52s	Fs	2.8	0.3	1.0	-"- -"- -"-	40	37	30	25	17	12	50	19	12	Good ductility and impact toughness.
Extruded Structural Shapes	8	B107-41T	8	M-314c(e)	1	11320(e)	520		57s	J	6.5	0.2	0.7	As Extruded	42	38	27	23	15	10	58			Good strength and weldability.
					2	11320			3s	M		1.5		-"- -"-	35	30	23	16	6	3	42			Best salt water resistance.
	15	B107-41T	15	M-314c(e)	1	11320(e)	521		74s	X	3.0	0.2	3.0	-"- -"-	42	39	25	22	17	10	59			Heat treatable shapes.
	15a	B107-41T	15a	M-314c(e)	1	11320(e)	521		74s	X				-"- -"- ; Aged	43	40	28	25	14	8	62			
									58s	O	8.5	0.2	0.7	As Extruded	44	40	29	25	11	8	58			Improved strength.
									59s	G	10.0	0.1		-"- -"-	48	45	37	30	9	6				Highest hardness and strength.
	18	B107-41T					52		52s	Fs	2.8	0.3	1.0	-"- -"-	39	35	28	22	15	11				Good ductility and impact toughness.
Extruded Tubing			8	M-366b(e)	1	11318(e)	520		57s	J	6.5	0.2	0.7	As Extruded	40	36	19	17	9	7	55			Good strength and weldability.
			11	M-366b	2	11318			3s	M		1.5		-"- -"-	35	32	17	17	5	3	40			Best salt water resistance.
			15	M-366b(e)	1	11318(e)	521		74s	X	3.0	0.2	3.0	-"- -"-	40	36	19	17	9	7	55			Heat treatable tubing.
							521		74s	X				-"- -"- ; Aged	41	37	22	19	7	6	59			
									58s	O	8.5	0.2	0.7	-"- -"- -"-	42	39	29	25	5	4	60			Highest strength tubing.
							52		52s	Fs	2.8	0.3	1.0	As Extruded	35	32	16		11		50			Good ductility.
Press Forgings	8	B91-41T	8	M-126e(e)				4350A	57s	J	6.5	0.2	0.7	As Forged	41	38	25	22	9	6	56	21	15	General forging. Good ductility.
			11	M-126e					3s	M		1.5		-"- -"-	33	29	19	12	6	2	43			Weldable forgings.
	9	B91-41T	9	M-126e(e)		11321(e)		4360	58s	O	8.5	0.2	0.5	-"- -"-	45	42	30	24	7	5	69	22	16	Forgings, simple design. Strong.
	15	B91-41T	15	M-126e(e)					74s	X	3.0	0.2	3.0	-"- -"-	41	38	24	20	16	9	59		17	Heat treatable forgings.
	15a	B91-41T	15a	M-126e(e)					74s	X				-"- -"- ; Aged	42	38	28	22	14	7	62		17	
Hammer Forgings	16	B91-41T	16	M-126e					65s		3.5	0.2	(h)	As Hammer Forged	38	35	22	20	12	6	52	16	10.5	Hammer forgings.
										L	3.0	0.2	(i)	-"- -"- -"-	37	34	26	19	11	6	51		10.5	-"- -"-
Rolled Plate, Sheet & Strip	7	B90-41T					511			Eh	6.5	0.2		As Hard Rolled	45	39	34	28	9	3	70			Sheet with high strength.
										Ea				Annealed	39	(42 max.)	20		15	10	57			
	6	B90-41T					510		53s-H	Fh	4.0	0.3		As Hard Rolled	44	36	35	25	10	4	60			Sheet with high strength.
									53s-O	Fa				Annealed	36	(38 max.)	22		18	10	50	18	10	
	11	B90-41T	11	M-111	1	11317-B	51	4370	3s-H	Mh		1.5		As Hard Rolled	37	32	27	24	9	4	53			Sheet with best formability and salt water resistance.
									3s-O	Ma				Annealed	32	(35 max.)	16		15	12	44	17	8	
			8	M-111f	2	11317-B(e)		4381	57s-H	J-1h	6.5	0.2	0.7	As Hard Rolled	45	40	35	28	8	3				Sheet with best combination of strength and salt water resistance.
								4380	57s-O	J-1a				Annealed	40	(45 max.)	25		15	8				
			18	M-111f					52s-H	Fsh	2.7	0.3	1.0	As Hard Rolled	45	38	35	26	9	4				General purpose sheet alloy.
									52s-O	Fsa				Annealed	36	32	22		18	12				Good formability and strength.

(a) In 1000 psi. Yield strength is the stress at which the stress-strain curve deviates 0.2 % from the modulus line.
(b) Endurance or fatigue limit for 500 million reversals of the load, in 1000 psi.
(c) Solution heat treatment: Soaking at about 650 to 810 °F. followed by air quenching.
(d) Solution treatment followed by artificial aging at about 350 °F. (precipitation hardening).
(e) Compositions with 0.005 % Fe max. and 0.005 % Ni max., for improved resistance to salt water are required by these specifications. (Dowmetal J-1, O-1, X-1, and AMC 57s).
(f) Contains 0.5 % silicon.
(g) Extruded and stretched is the condition in which bar and rod is normally furnished.
(h) Contains 5.0 % tin. (i) Contains 3.5 % cadmium.
(j) Aeronautical material specification, Society of Automotive Engineers, Inc.

ALUMINUM BRONZES COMMONLY USED IN AIRCRAFT

ALUMINUM BRONZES COMMONLY USED IN AIRCRAFT

Compiled by W. W. Edens, Ampco Metal Inc.

Reference Number and Nominal Composition[a]	Condition	Specification Met	Tensile Strength, Psi.	Yield Strength, Psi.	Proportional Limit, Psi.	Elongation in 2 In., %	Reduction of Area, %	Brinell Hardness, (3000 kg)	Impact		Endurance Limit, Psi.[b]	Compression Tests		Lb. per Cu. In.	Representative Uses in Aircraft
									Izod Ft.-lb.	Charpy Ft.-lb.		Elastic Limit Psi.	Ultimate Psi.		
Alloy I. 89.5 % Cu 9.5 % Al 1.0 % Fe Structure A_2	Sand Cast	PWA-135	70 000 75 000	25 000 32 000	12 000	30 40	30 40	115 126	32 38	26 30	In Test	25 000	In Test	0.270	Bushings; Gears
	Centrifugal Cast		77 000 82 000	27 000 34 000	14 000	25 30	25 30	121 134							Bushings; Gears
	Heat Treated	QQB-671 Grade "B"	78 000 88 000	38 000 48 000	22 000	22 30	24 32	143 156	25 30	17 24	In Test	35 000	In Test	0.270	1. Gun Bearings 2. Gun Mountings 3. Tail Wheel Bushings 4. Landing Gear Nuts 5. Tail Wheel Trunnion Yokes
	Forged		75 000 80 000	26 000 30 000		30 35	20 25	121 134						0.270	1. Motor Parts 2. Bearing Liners 3. Cam Supports 4. Thrust Pads 5. Retainer Plates
Alloy II. 88.5 % Cu 10.5 % Al 1.0 % Fe Structure E_1	Sand Cast		70 000 80 000	38 000 45 000	15 000	12 20	14 20	131 143	28 34	20 26	In Test	30 000	In Test	0.270	1. Bushings 2. Gears 3. Corrosion Resistance
	Centrifugal Cast		77 000 85 000	40 000 47 000	16 000	10 16	10 16	137 153							Bushings; Gears
	Heat Treated		80 000 95 000	42 000 50 000	30 000	12 15	13 17	165 179	25 30	15 20	In Test	45 000	In Test	0.270	1. Idler Gear Bushings 2. Blade Bushings 3. Master Rod Bushings
Alloy III. 88.5 % Cu 8.6 % Al 2.9 % Fe Structure A_1	Sand Cast	46B-18C QQB-671 "A"	60 000 70 000	22 000 27 000	14 000	22 27	22 27	109 124	75	60	In Test	18 000	119 200	0.279	1. Tail Wheel Bearings 2. Landing Gear Control Bearings 3. Gun Slides 4. Gun Mountings
	Centrifugal Cast		70 000 77 000	27 000 34 000	14 000	25 30	25 30	116 131							Bushings for Tail Wheel Strut and Landing Gear Control
	Forged	46B-17b "B" QQB-666 "B"	82 000 90 000	32 000 38 000		25 30	25 30	143 156						0.270	
	Extruded	46B-17b "B" QQB-666 "B"	88 000 94 000	48 000 55 000		25 30	30 40	179 187				58 000		0.270	
	Hot Rolled	46B-17b "B" QQB-666 "B"	95 000 105 000	55 000 65 000		18 22	20 25	170 187				48 000		0.270	
Alloy IV. 86.5 % Cu 10.2 % Al 3.3 % Fe Structure A_2[c]	Sand Cast		70 000 80 000	32 000 37 000	16 000	18 22	16 20	131 156	35	28		22 000	124 600	0.275	1. Bushings 2. Gears 3. Tail Wheel Strut and Landing Gear Control Bearings 4. Valves Guides 5. Pump Bodies
	Centrifugal Cast		77 000 85 000	35 000 40 000	17 000	15 20	15 20	137 160							1. Bushings 2. Gears 3. Shock Absorber Piston Bearings 4. Tail Wheel Strut Bearings 5. Landing Gears 6. Packing Nuts 7. Tail Wheel Packing Nuts 8. Orifice Retainers
	Forged		87 000 95 000	35 000 40 000		25 30	25 30	150 156							1. Landing Gear Shock Absorber Pistons 2. Piston Bearings 3. Gears 4. Packing Nuts
Alloy V. 85.0 % Cu 11.0 % Al 3.7 % Fe 0.3 % Others Structure E_1	Sand Cast		77 000 85 000	35 000 42 000	18 500	10 14	6 10	159 183	25	17	25 000	30 000	136 430	0.273	1. Wear Plates 2. Hinge Plates 3. Control Gears 4. Valve Seats 5. Pump Bodies
	Centrifugal Cast	PWA-241	82 000 90 000	38 000 44 000	19 000	8 12	6 10	166 187							1. Blade Bushings for Electric, Hydromatic and Controllable Pitch Propellers 2. Propeller Hub Nuts 3. Propeller Rear Cone Bearings 4. Pump Parts
	Heat Treated	Curtiss 3300	95 000 105 000	43 000 50 000	31 000	10 15	12 18	179 207	15 20	20 25	35 000	45 000	150 000	0.274	1. Landing Gear 2. Tail Wheel and Strut Bushings 3. Retracting and Packing Nuts 4. Orifice Retainers 5. Wear Plates 6. Propeller Hub Nuts 7. Front and Rear Propeller Cone Bearings
	Heat Treated	Air Corps 11076	90 000 100 000	45 000 55 000	34 000	3 7	3 7	202 223	18 22	11 15	In Test	50 000	155 000	0.274	
Alloy VI. 82.5 % Cu 13.2 % Al 4.3 % Fe Structure D_1	Sand Cast		70 000 80 000	42 000 Min.	In Test	1 4	0 4	285 311	10	6 7	In Test	50 000	160 000	0.258	1. Drawing and Forming Dies for Carburetor 2. Fuselage and Other Stainless Steel and Aluminum Parts
	Centrifugal Cast		70 000 80 000	42 000 Min.	In Test	1 4	0 4	285 311	10	6 7	In Test	50 000	160 000	0.258	Dies
Alloy VII. 81.4 % Cu 14.1 % Al 4.5 % Fe Structure D_2	Sand Cast		75 000 85 000	45 000 Min.	In Test	0 2	0 2	321 352	9	4	In Test	65 000	171 000	0.257	Drawing and Forming Dies
	Centrifugal Cast		75 000 85 000	45 000 Min.	In Test	0 2	0 2	321 352	9	4	In Test	65 000	171 000	0.257	1. Hydromatic Propeller Cam Rollers 2. Dies
	Extruded	HSP-22	80 000 90 000	50 000 Min.	In Test	1 2	1 2	321 358						0.257	Cam Rollers
Alloy VIII 81.3 % Cu 10.7 % Al 4.0 % Fe 4.0 % Ni Structure A_2	Forged and Heat Treated	(d) HSP-16	96 000 102 000	55 000 60 000	30 000	10 15	10 15	190 217	15 20	25 30				0.280	Propeller Locking Nuts
	Heat Treated	Wright 6852-A	90 000 96 000	42 000 50 000	27 000	8 12	8 12	217 229	10 15	20 25				0.280	

Note: (a) Microstructures are as follows: A_1 Alpha; A_2 Alpha + Beta; E_1 Alpha + Eutectoid; D_1 Beta + Eutectoid; D_2 Beta + Eutectoid

(b) Based on 100 000 000 cycles of stress

(c) Uses for Alloy IV: Extruded shapes: 1. Landing gear torque arm bushings 2. Landing gear and strut bushings and parts
Rolled rod and sheet: 1. Windshield wiper parts 2. Landing gear and strut bushings and parts 3. Wear plates 4. Defroster parts

(d) Aluminum is 10.5 %

Modern Bearings Sometimes Have Three Very Thin Layers of Alloy Within a Steel Back. Photo by Van Fisher at Cleveland Graphite Bronze; 100% inspection for thickness; tolerance: 0.00025 ± 0.000125 in.

An ancient example of this art of localizing properties, that of casehardening, has in recent years been supplemented by nitriding and the cementation of metals like aluminum, zinc and silicon. More recently various types of surface hardening by flame or electrical induction heating have come into practical use, in which localization of heat treatment rather than localization of chemical composition is effected.

Electroplating, a comparatively old art, has very recently been enlivened and enriched by the addition of heat treatment processes, which produce, by diffusion, alloy layers of improved corrosion protection as compared with the simple electrodeposited surfaces.

A very powerful technique for "localized" property production is, of course, that of powder metallurgy just mentioned, and little imagination is required to picture interesting possibilities in this direction, many of which are being realized, such as that of bearings with steel backs and powder-compacted bearing surfaces and powder-clad articles of various sorts.

Another example of useful segregation of incompatibles by the powder method is in the pressure compacting of magnetic powders. These are coated with a thin insulating film, such that the powder compact has excellent magnetic permeability, but also much higher electrical resistivity than is possible by the use of the magnetic material itself in dense form.

The list of these "property localizer" techniques is growing and I mention them principally to emphasize my belief that collectively they represent an important avenue of future metallurgical progress — an avenue that can lead us through much unexplored territory to opportunities as yet unutilized. It would appear probable that progress in the use of arts of this type would be achieved particularly in the production of corrosion resistant and of abrasion resistant articles, of which surface and core characteristics may well be quite different. But one can imagine many other fruitful directions in which this art might take form.

Specific Materials Are Urgently Sought — If we listen to the comments of engineers in other fields — chemical, electrical, mechanical, civil — we receive the impression that in spite of all the progress alloy metallurgy has made in the past, the art still falls far short of being able to supply the materials desired and required by engineering and industry. For it is their common comment that progress in their art is held

back to lack of better materials, and they emphatically include metallic materials in this category. Such comment inevitably reminds each of us of specific problems which urgently need solution, or of which the solution would obviously have substantial economic value.

These problems are often most neatly posed in the form of a hypothetical alloy material having certain specified properties not yet achieved in practice. I should like to cite a few of these, which would appear to have some promise of realization.

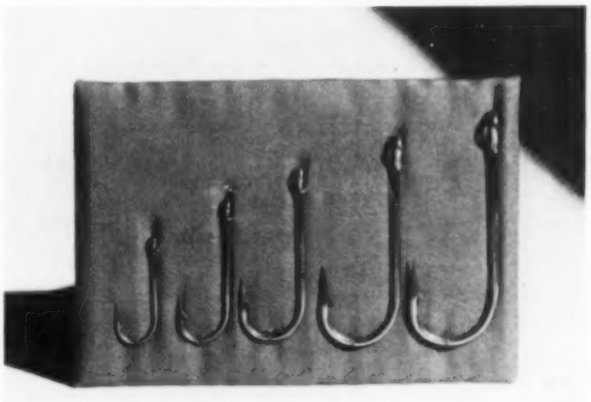
Creep Resistant Materials

There are probably few such conceivable ideal materials which would be more warmly welcomed than a steel of higher creep strength at temperatures from 1000 up to 1300° F. and even higher. The economic contribution of improved materials of this sort in permitting higher steam generating temperatures, with resulting higher heat engine efficiency, is obvious. Much progress has already been made in the development of creep resistant steels, as well as in our practical knowledge of creep, and this is reflected in the specifications in the present A.S.M.E. Boiler Code of permissible working stresses for steels at temperatures as high as 1000° F. And the alloy steels we have available today for medium high temperature service — many of which were developed especially for it — possess creep strength values of from 5000 to 7000 psi., a figure very much higher than those of the carbon and alloy steels used for such service 15 years ago.

Resistance to creep, within this particular and important temperature range, is a "structure sensitive" property, and I believe that evidence favors the belief that we have not yet found the ceiling of creep resistance at these temperatures. Creep depends much on "keying" obstructions to slip and plastic deformation, and not until we understand better the possibilities of the stabilization of structural barriers to slip, and (equally importantly) the possibilities of precipitating and maintaining such barriers at higher temperatures, shall we have attained reasonably this important goal. And beyond that is the possibility of pushing forward to higher temperatures and utilizing the higher creep strength values of the austenitic steels which possess no such obvious temperature ceiling of usefulness as the lower critical temperature of ferritic steels.

Another important hypothetical material, which seems not impossible of realization, is a copper alloy of high conductivity and high strength. Cadmium-copper and chromium-silicon-copper represent today a considerable step forward in that direction, but it would seem that the art of precipitation hardening might be capable ultimately of producing a copper alloy of 100,000 psi. tensile strength and of conductivity approaching perhaps 90%. This would have to be a copper in which the precipitation of alloying components could be rendered practically complete, thus assuring both high conductivity of a pure copper matrix and high strength due to obstruction to plastic flow. The value of such a material in high tension transmission lines is of course obvious. Its unavailability leads today to the development of designs, both in copper and aluminum, in which the conducting metals are in one way or another associated with high strength steel wire.

Another hypothetical material of importance, whose realization most of us have probably speculated about at one time or another, is malleable gray cast iron. I mean of course gray iron, of which the graphite structure is such as to confer some malleability in the cast condition without heat treatment. Provided its production were not too involved in character and too great in cost, such a material would certainly be a welcome addition to the group of our major alloy materials. I don't consider it without the bounds of possibility that the many lines of research now going on in the control of graphite structure in gray iron may before long show us the way to such a new material.



Corrosion Resistance in Salt Water, Strength and Toughness Are Combined in These Hooks of "Z" Nickel, a Heat Treatable Alloy Containing 98% Ni

I could mention many more such eagerly sought new materials. Better permanent mold alloys are desired to render the die-casting of brass and iron possible. Better non-galling materials would be welcomed for high temperature valves. In a recent industrial survey by "The Research Advisory Service" some 90 specific alloy problems of this type were posed, solutions of which were considered to have capital industrial importance (and some of which, it may be remarked, are already reasonably well solved but apparently not yet well advertised).

The many unsolved material problems of this type certainly have a tremendous value in stimulating metallurgical discovery and invention. They originate usually with consumers and users of alloys, who supply alloy producers with ever-changing competitive goals and objectives for their effort. In the two decades since the first World War, we have witnessed a consumers' market in metals and alloys and to that fact I feel we owe much of the progress in alloys. It has been a market characterized by intense competition between materials and by ever-increasing volume and quality of metallurgical and engineering effort expended on the job of matching the supply of alloys to the demand, and to the competition offered by non-metallic materials. The well organized and large metallurgical research and service departments of producers and users of metals constitute excellent testimony of this fact. The cost of producing metallic products tends to go down with technological improvement, but the cost of servicing these products certainly appears to be on the increase!

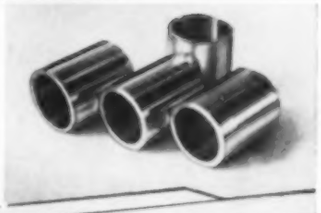
New Knowledge of the Structure of Metals Will Bring Alloy Engineering Advance — There is, finally, another major aspect of our present position in alloy metallurgy, which strongly suggests that the future still holds some most intriguing and probably major developments. In spite of the rapid progress in metallography during the past 30 years, we are certainly only at the threshold of a really satisfactory understanding of the inner structure of metals.

We know much about grain structure and phase equilibria, we know something of the lattice structure of crystals, but of the nature of the atomic forces and movements which determine the basic characteristics of alloys we are only now beginning to have a glimpse. The researches and speculation of metallurgists and physicists, with the aid of the newer and often powerful techniques of X-ray and electron diffraction analysis (and possibly now of the electron microscope), will surely afford us much more adequate understanding of structure and of atomic movement than ever before.

It is hardly a very daring prediction that this better basic understanding of metals will permit forward strides of a major character in our ability to manipulate and improve useful alloy properties. I suggest the possibilities, both in control of the properties of alloys as well as in their fabrication, which may result from our better understanding and control of ordered crystal orientation in alloys; and the possibilities of developing enhanced physical properties, particularly in the electrical and magnetic fields, as a result of our recently enhanced knowledge of so-called "ordered" atomic structures. And again, there are certainly additional values, yet undeveloped, to be secured from better understanding and control of alloy transformations, including particularly those effects which flow from the controlled arrest of transformations at various stages.

May I suggest also in this connection the stimulating value which the recent development of so-called "plastics" is bound to have on alloy metallurgy. When, as has been recently announced, a plastic material of crystalline nature can be developed by the chemists, having a tensile strength as high as 60,000 psi., together with considerable plastic ductility, then, both from the scientific standpoint and from the viewpoint of commercial competition, alloy metallurgists must take heed for their wares!

The simple conclusion to which these remarks have pointed is perhaps a trite one — that notwithstanding what most of us have considered to be a very accelerated pace of progress in alloy metallurgy in the last 25 years, we are nevertheless but on the threshold of still more striking and important developments of varied character and type. When we consider how urgent is the engineering need fer better alloy materials, when we note current accomplishment in improving both the performance and the fabrication of alloys, and when finally we think of the new avenues and vistas being opened to us by physical research and thought devoted to the nature of solids, we can surely come to no other conclusion but that we are still "on the make" in alloy metallurgy, and that most of us will probably live to experience even greater astonishment over the future turns which progress will take than ever in the past.



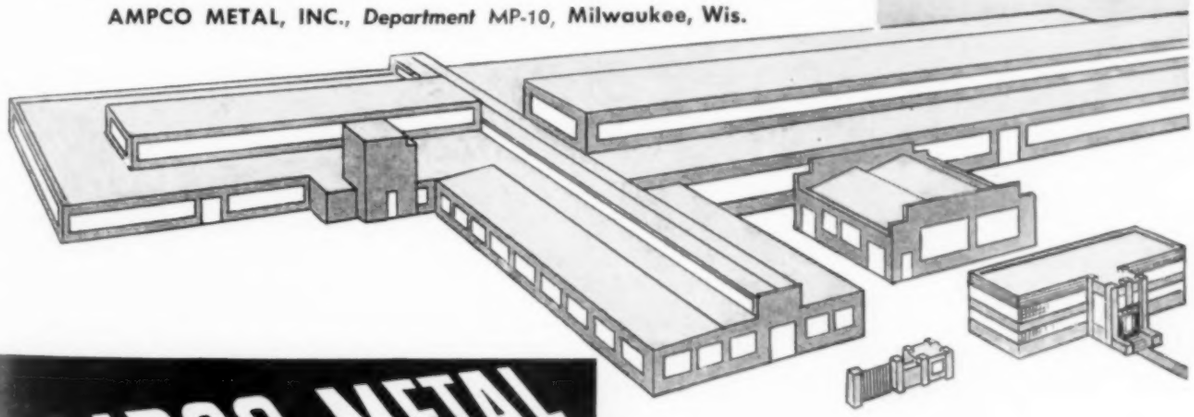
In the Tools and Weapons of Defense

Like hundreds of other plants, the Ampco foundries are all out for defense. Today 98.5% of the output is devoted to defense activities. Ampco Metal and Ampco-made bronzes are being used in aircraft, machine tools, ordnance, and other equipment where the sturdy, wear-resistant qualities of Ampco alloys are essential.

For years before the defense program was under way, Ampco was serving American industries, helping build the quality for which American products are famous. The high tensile strength, controlled hardness, and resistance to wear and corrosion of Ampco-made bronzes were early recognized by designing engineers as necessary for satisfactory equipment performance.

Catalog number 22—brand new—shows why Ampco Metal is preferred by defense contractors.

AMPCO METAL, INC., *Department* MP-10, **Milwaukee, Wis.**



AMPCO METAL

The Metal Without An Equal

AMPCO FOUNDRIES—plant capacity has been doubled, making this the largest foundry in the country devoted primarily to the production of aluminum bronzes of controlled analyses.

the corrosion of Duralumin*

CORROSION of alloys of the duralumin type consists of surface pitting and intercrystalline penetration; which variety depends largely on the rate at which the material is cooled from the solution treatment temperature of approximately 950° F. Material that has been cooled relatively slowly by quenching in hot water is mostly corroded at the grain boundaries, which action may penetrate deeply without leaving marked evidence on the surface, but be very damaging to the ductility and strength of the material, especially of sheets. The same alloy, however, if cooled more quickly by quenching in cold water, is practically immune to the intercrystalline type of corrosion, though its initial tensile strength and other properties do not differ essentially from those produced by quenching in hot water. Any corrosion that occurs is then generally of the pitting type.

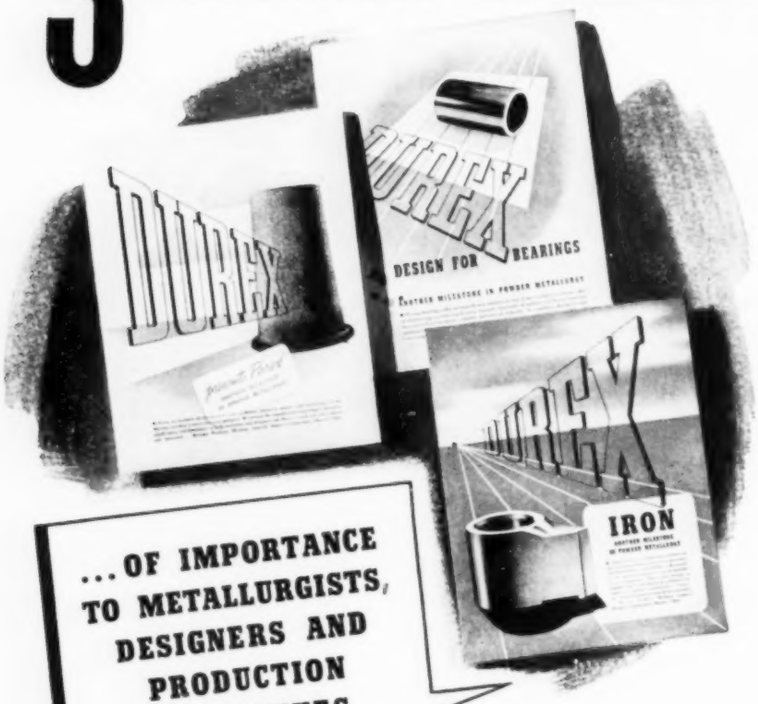
Accelerated corrosion tests are slow and need specimens cut from the article. A laboratory test has been developed by H. L. LOGAN of the National Bureau of Standards in which potential measurements predict the type of corrosion which may be expected. The potential measured was the e.m.f. of a cell in which a small area (0.8 to 1.0 sq.cm.) of the metal surface was in contact with a saturated solution of potassium chloride, which in turn was connected to a standard calomel electrode.

The surface film on the metal tested should be completely removed by fine emery, and no electrode potential measurements were made until at least 6 min. after the surface preparation had been completed.

All specimens which gave an electrode potential more electronegative than —0.672 volt were susceptible to intercrystalline corrosion, usually severe, and all with potentials less electro-negative than —0.648 volt were immune. A potential of —0.657 volt at 25° C. was selected as the critical value. Of all the 700 specimens studied between 85 and 90% were correctly classified. It is not possible to predict the *degree* of intercrystalline attack from potential measurements, but the prediction of susceptibility is much more certain for specimens liable to severe attack than for those which are only slightly affected. Difference of copper content in the alloy was not an appreciable source of error.

*Abstracted from "American Work on the Corrosion of Duralumin" in *The Metallurgist*, June 27, 1941, p. 18.

3 NEW BULLETINS ON POWDER METALLURGY



...OF IMPORTANCE TO METALLURGISTS, DESIGNERS AND PRODUCTION EXECUTIVES

These brand new bulletins carry valuable data on products engineered by Moraine from metal powders: Durex Iron, Durex Oil-retaining Bearings, and Porex Filters. *For metallurgists,* they contain helpful new information on physical properties, structure, and applications of Durex products. *For designers,* they give facts on tolerances, shape and size possibilities and limitations. *For production men,* they suggest time and money-saving short-cuts in processing methods, show how Durex and Porex parts save materials, improve product performance, often do jobs never done before. Any or all bulletins sent promptly on request: Porex Filters: Form 101M, Durex Bearings: Form 102P, and Durex Iron Parts: Form 103P.

MORAINE

Pioneer in Powder Metallurgy

MORAINE PRODUCTS DIVISION, GENERAL MOTORS CORPORATION, DAYTON, OHIO

The author believes that structure and properties of steel are more indicative of its utility than chemical analysis, and discusses the heat treatment (both from a theoretical and a practical standpoint) that will give the best properties to low alloy and plain carbon steels

Getting Maximum Results From Carbon and Low Alloy Steels

THE WORK which has been done over the last few years in studying hardenability, the transformation of austenite, and the effect of special deoxidizers, has given us a new insight into the possibilities of heat treated steels.

We can now approach the problem of proper steel selection for a given application, at least metallurgically speaking, on a fairly firm ground as compared to our position not so many years ago. It is possible to fit a hardness gradient in a given part to the stresses met in service and to balance carbon content, grain size and alloy content to insure satisfactory performance at lowest cost.

Before a steel of definite analysis and its treatment is selected for a certain part we must know the conditions under which it operates. An intelligent selection *cannot* be made until these conditions are known. Possible internal stresses, the degree of ductility required, the importance of machining costs and such factors as resistance to abrasion, temperature and shock loads, all affect our choice of steel and its treatment. No metallurgist can make sure his recommendation is the best until he is familiar with the processing and working conditions of the part for which he is specifying.

One of the most important subjects which the engineer and metallurgist can consider is the stress distribution in the finished heat treated piece. This study involves not only the estimated stresses caused by extreme service condition but also internal stresses incidental to heat treatment. In parts such as shafts and similar members subjected to torsion and bending stresses it is quite obvious that the maximum stress is concentrated at the surface of the work, so that every effort should be made to provide a surface which is free from stress raisers or decarburization which would lead to low strength and low fatigue resistance. If the surface is subjected to alternate tension and compression it becomes of primary importance to avoid the weakening effects of decarburization and poor quenching. Service stresses are generally tension and compression, although in a few applications we find that compression loads are of greatest importance; thus, in gear teeth we have the possibility of failure by tension at the root of the tooth or by spalling by compression loads along the pitch line.

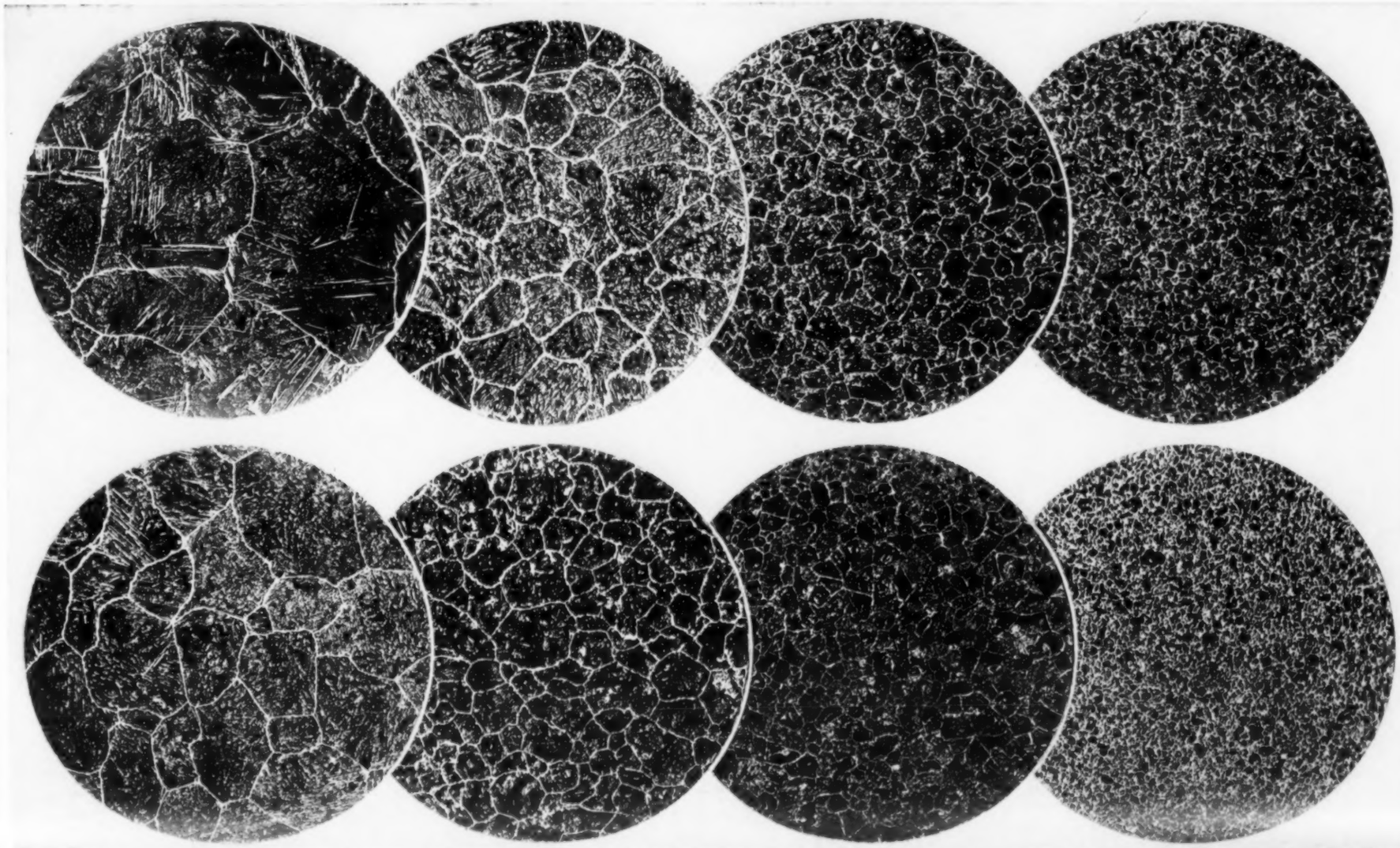
Where failures occur in shafts or other parts due to bending stresses which result in fatigue failures starting at the surface, the metallurgist often increases the alloy content of the part. Since this results in an increase in hardness at the center of the shaft he is apt to be misled into thinking that the improvement was due to that circumstance. As a matter of fact, the improvement was probably due to the

By Harry W. McQuaid
Assistant Chief Metallurgist
Republic Steel Corp.
Cleveland, Ohio

Standard Grain Sizes for Steels

Carburized and slowly cooled to develop cementite network. Magnified 100 diameters. Micros courtesy Timken Roller Bearing Co.

Grain Size No. 1; Up to 1½ per sq.in. | No. 3; 3 to 6 grains per sq.in. | No. 5; 12 to 24 grains per sq.in. | No. 7; 48 to 96 grains per sq.in.



No. 2; 1½ to 3 grains per sq.in. | No. 4; 6 to 12 grains per sq.in. | No. 6; 24 to 48 grains per sq.in. | No. 8; More than 96 grains per sq.in.

improved structures obtained close to the surface of the shaft by the increase in alloy, and probably the same physical results could have been obtained by an increase in carbon content with careful heat treatment without much alloy.

Since so many important machine parts are most highly stressed at the very surface, and fail — when they do — by breakdown of the structure at the very surface, it is surprising that so very little has been published regarding the effects of various types of quenched structure on fatigue limits, or on the localization of stresses. It should be superfluous to remark that the *surface* feels the greatest effect of the quenching practice and it is quite certain that the quenched structure is a very important factor in the ability of a hardened steel to withstand alternating stresses.

Since the surface zone is so often the area of high stress it is obvious that there is frequently very little advantage in using high alloy content for higher strength or wear resistance because *carbon* is the essential strengthening element after all. It is my experience that equal or perhaps better results can be obtained by using a lower alloy content with higher carbon, or by using a quench severe enough to insure homogeneous martensitic structures in the lower carbon type. When enough alloy is used in parts of ordinary size to obtain the best structure in an oil quench, it sometimes happens that the part hardens so deeply that the internal stresses set up counteract the beneficial effects of the improved outer structure.

The warpage incurred by a severe water quench must be corrected by a carefully controlled hardenability gradient and maximum speed of introduction into the quench, but the medium carbon steels — even when quenched in water or caustic — are difficult to quench fully if the manganese is on the low side.

Steels for "Timed" Quenching

On simple shapes and with special equipment, "timed" water or caustic quenching of the ordinary carbon steel will produce a satisfactory structure, but the subsequent drawing temperature will generally be so low that it is difficult to avoid high residual stresses. To raise this drawing temperature the steel for such treatments should contain sufficient alloy; this would ordinarily require approximately 1% of manganese with smaller percentages of such elements as chromium, molybdenum or nickel. For large work which must have high physical properties throughout, it is of course necessary to increase the alloy content to a degree depending upon the severity of the quench and the depth of hardening desired.

Steel users are still bound by some of the practices necessary in the days before grain size and "abnormality" were controlled by the steel maker, in that there is a tendency to specify lower carbon than is necessary for best results, especially with oil quenched steels, because of its effect on machinability and warping. With the fine-grained types of medium carbon steel, however, the carbon usually can safely be carried 5 to 10 points higher than would be considered satisfactory for a coarse-grained steel. The first effect of this higher carbon is to improve the "hardenability" of the work, and to improve the quenched microstructures especially at the surface. In parts where the stress is maximum at the surface, especially in oil quenched material, a carbon content close to eutectoid (if it can be satisfactorily handled) will result in surface structures having the best combination of strength and ductility at high hardness. The beneficial effects of higher carbon are of course offset by internal stresses which develop in small or non-uniform sections. If the heat treatment allows some austenite to be retained, a higher carbon may be a disadvantage because it increases the amount of austenite in the surface, but this is a rare occurrence if the work is drawn.

The tool hardener of years ago, who quenched his work in water until the "vibration stopped" and then transferred it to an oil bath, had never heard of the "S" curve, or "hardenability control", but he was following a heat treating procedure which these developments indicated to be quite proper. He was trying to get maximum hardness and thorough quenching without endangering the quenched piece by the cracking which occurred when the work reached too low a temperature. He knew that the piece so treated would have much better properties than when treated in the oil alone, and would be freer from cracks or high internal stresses than if quenched completely in water.

Most of us who have had experience with water quenching know that, if the carbon is sufficiently high and the hardenability sufficiently great, quenching to room temperature will often result in such high internal stresses that the piece will be excessively distorted and perhaps actually cracked. On the other hand,

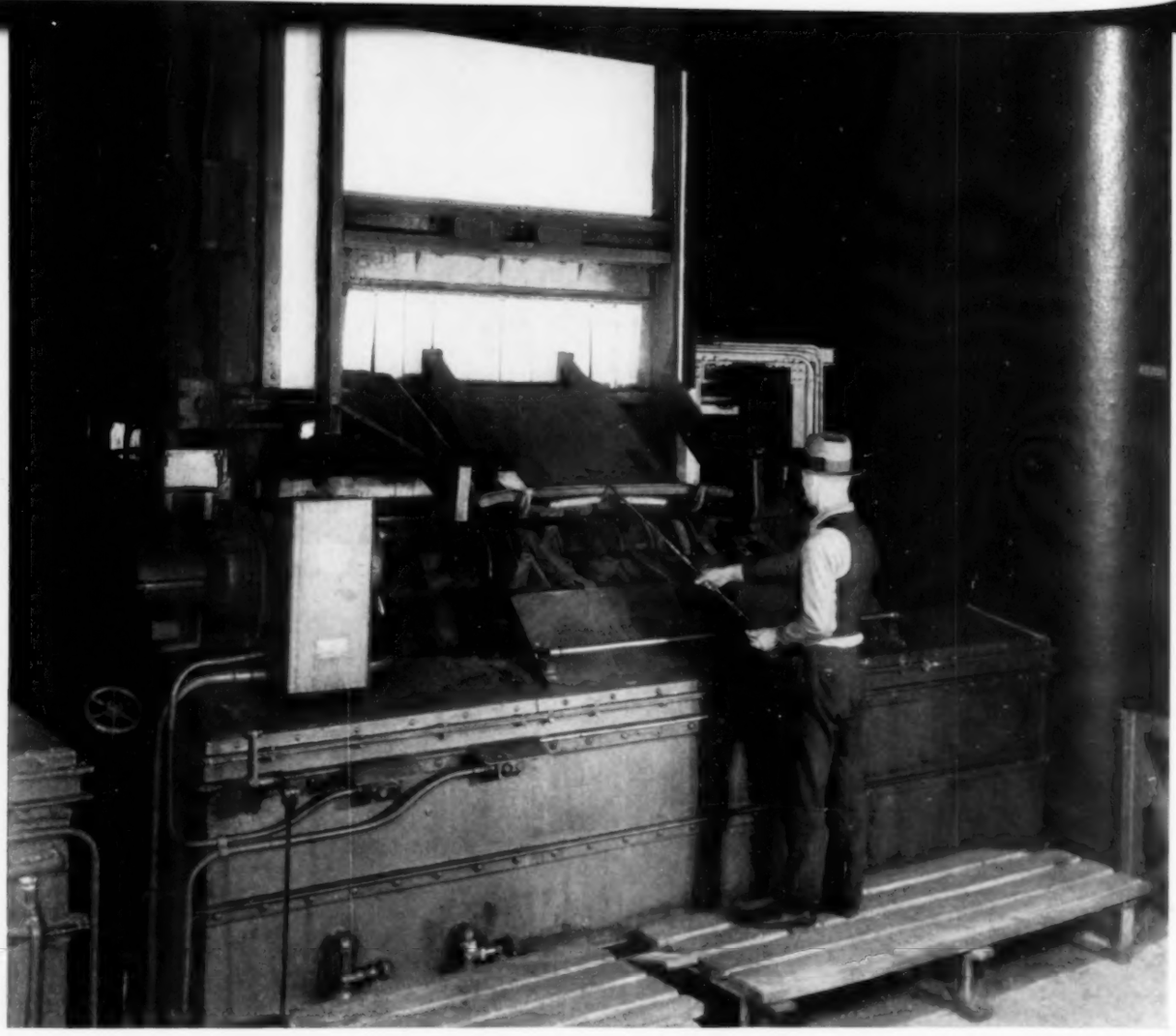


Fig. 1 — Front Axle Slides Out of Furnace Into Quenching Machine, Held Tightly in Fixture, Immersed in Caustic for Timed Interval, Delivered Still Warm at Rear, and Pushed Immediately Into Drawing Chamber, Below the Quenching Hearth. Courtesy Ford Motor Co.

"timed" water quenching, if it can be properly worked out, will usually produce a structure which is definitely superior to the slower oil quenched structure, even in many steels which would produce the desired hardness in oil. Experience has shown that if the work is non-uniform or small in section it is difficult to get it out of the water quench and into the oil with any uniformity of results. "Timed quenching" therefore, is most adaptable to sections of simple shape and large production which would permit automatic handling and timing. As an alternative to transferring the work from water to oil it may be transferred to a hot salt bath at 300° F. until uniform in temperature and then placed in the draw furnace or cooled in air.

A specific case can be profitably studied: The old style Ford truck axleshaft of S.A.E. 1040 grade, quenched in a 10% sodium hydroxide solution for 27 to 34 sec. and then transferred directly to the drawing furnace, becomes a machine part with properties apparently equivalent to oil quenched shafts of high alloy content. This cycle was developed to obtain a scale-free quench and a shaft of satisfactory properties, free from quenching cracks or soft areas. The design was such that this shaft was very sensitive to quenching cracks and a longer time than 34 sec. in the quench caused cracks in the integral gear blank forged on one end. In fact, if the steel were just a little too high in hardenability it became very difficult to prevent these cracks. However more than a million parts must have been made by this particular method in the last 15 years, indicating that the heat treating procedure has been very satisfactory.

Most heat treating equipment today is based on the supposition that a water quench requires only an open tank of water, and an oil quench a similar tank filled with oil. Not many heat treating departments have given much thought to bringing the water in contact with the surfaces to be quenched so as to eliminate steam formation. In a few cases jets and violent circulation are used and occasionally the advantages of the caustic quench are realized. The

importance of proper quenching in obtaining structures that give maximum properties, as well as a specified hardness reading, is not nearly so well recognized as it should be. With oil quenching, the problem is even greater. Since poor oil quenching generally results in raising the alloy content of the steel and hence more expense we should give much thought to the adequate jets and circulation in the oil.

In oil quenched parts (and also in water quenched parts of any mass) there is considerable difference in the cooling rates at the surface and at the center of the work. The surface in a water quench cools to the bath temperature almost immediately if circulation is sufficiently vigorous to remove instantly any steam formed at the surface. In an oil quench the surface cools much less rapidly since it is extremely difficult to remove vaporized decomposition products of the oil in contact with the hot steel. It is for this reason that much more vigorous action is required in an oil bath to achieve maximum quenching speed. It is difficult to obtain a homogeneous martensitic structure in steels in the low alloy, medium carbon range. Nearly always such oil quenched steels contain some ferrite or transition products in the grain boundaries, so that the water quenching will definitely improve their properties at or near the surface — providing care is taken to avoid too fast a cooling in the high stress range, that is, below 300° F.

Water Quenching of Alloy Steels

While water quenching of alloy steels is uncommon, it has considerable merit where it can be applied. Its use of course is limited by excessive austenite formation, by warpage, and by high internal stresses due to thermal shock. All these troubles can of course be eliminated by time quenching in water and transferring to a draw furnace, a hot salt bath, or, in some cases, even to an oil bath. It is not recommended, however, that such treatments be tried except in special circumstances, such as quenching large alloy steel shafts (especially if the carbon content is low). Sometimes such a procedure has resulted in a very definite improvement over an oil quench.

The determination of the time in the water quench would either be done by trial or by a study of the JOMINY hardenability curve or of some other hardenability test. It is only necessary to get the work cooled sufficiently fast to insure transformation to a uniform martensitic structure, which means a fast cool approximately half way down to room temperature. The *time* required for transformation can be determined from the hardenability curve without much difficulty providing the section is uniform, but not so easily in work having a very non-uniform section.

Table I — Effect of Special Alloy Addition on Properties of S.A.E. T-1340 Steel

ANALYSIS	NO ADDITION	WITH ADDITION
Carbon	0.36%	0.39%
Manganese	1.68%	1.73%
Nickel	0.04%	0.04%
Chromium	0.10%	0.10%
Physical Properties After 1550° F. Oil Quench, 450° Draw		
Tensile strength	233,000 psi.	263,000 psi.
Yield point	218,000 psi.	247,000 psi.
Elongation in 2 in.	7.0%	12.2%
Reduction of area	28.0%	49.9%
Izod impact	11.5 ft-lb.	18.0 ft-lb.

Traces of Rarer Elements Develop Great Hardenability

There have been developed some special alloy additions to medium carbon steels which make it possible to obtain some remarkable combinations of ductility and strength at high hardness. These alloys are combinations of vanadium, titanium, boron, aluminum, and perhaps others, which, when added in relatively minute amounts, increase greatly the depth of the hardness obtained on quenching. They are usually added in the ladle or the mold to steels which have been already finished according to standard melting practice. Table I shows some of the properties which have been obtained with such an addition to the straight manganese type.

As another example, the treatment of an S.A.E. 1040 steel with approximately 1 lb. of dehydrated borax per ton results in a boron content of approximately 0.003%. When normalized in 1 in. squares at 1600° F., turned to 0.530 in. round, quenched in oil from 1550° F., and drawn at 450° F. the following remarkable properties were developed in standard 0.505-in. tensile tests:

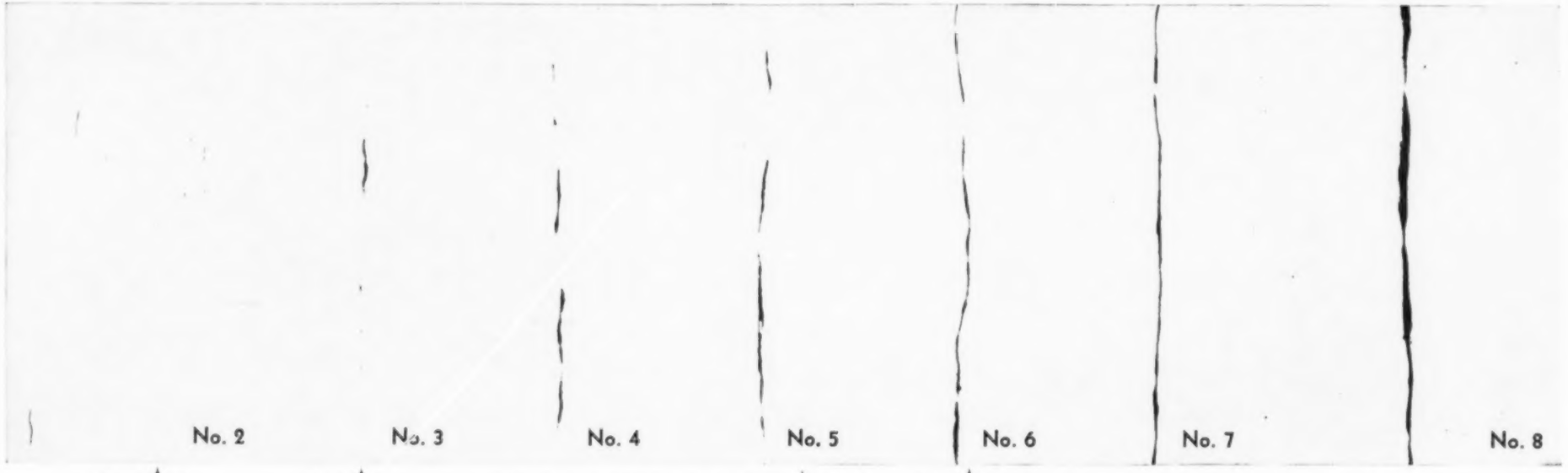
	NORMAL STEEL	BORAX TREATED
Tensile strength	129,000 psi.	255,000 psi.
Elongation in 2 in.	19%	11%
Reduction of area	63%	43%
Rockwell hardness	C-25	C-50

(Text continued on page 458)

Rating of Inclusions ("Dirt Chart")

In use by Chevrolet Motor Co. *Developed by George W. Walker*

(General Motors Standards Book shows four types, A to D, of each variety as indicated in this style of type.)



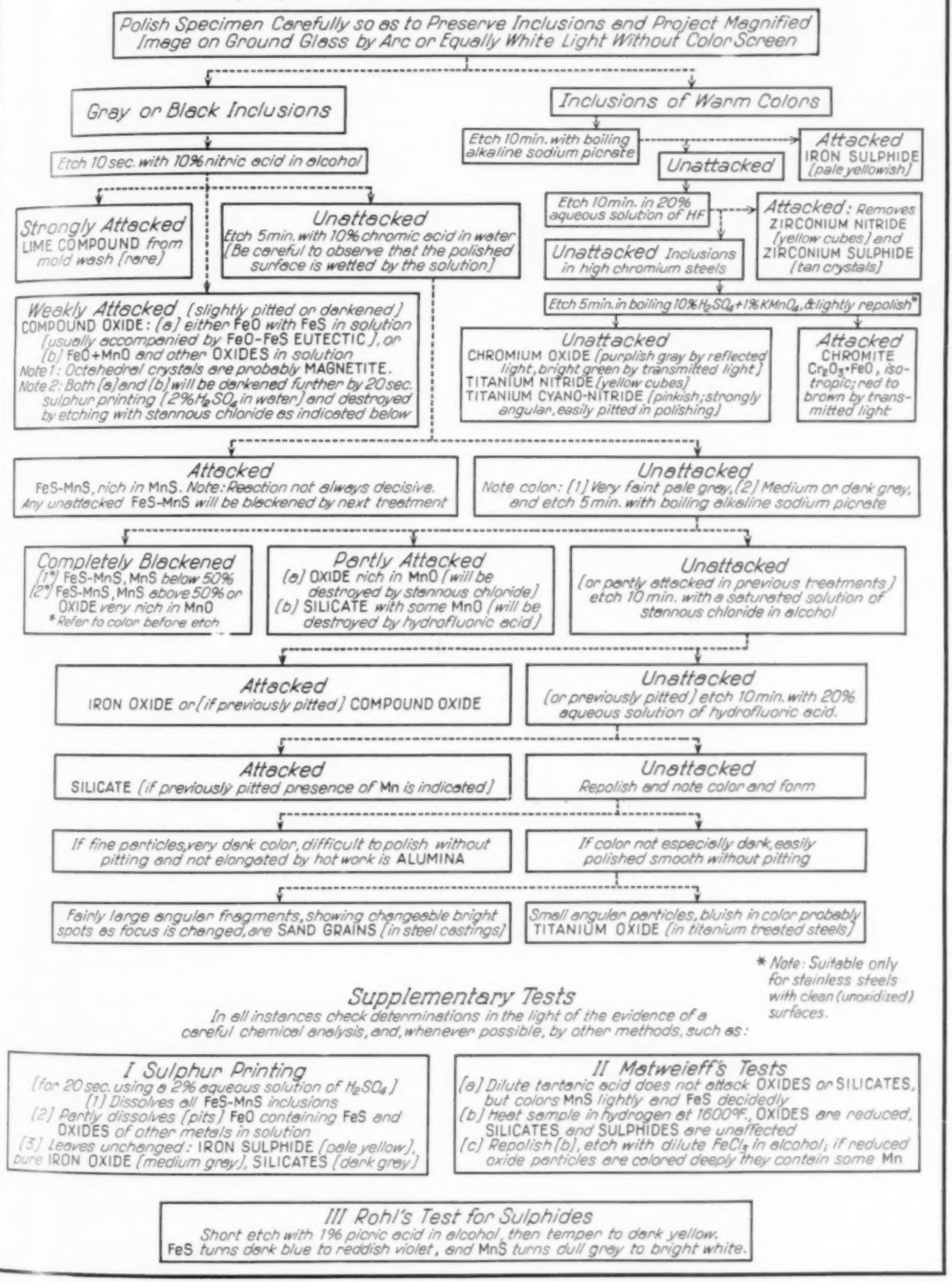
G.M. ↑ A G.M ↑ B Silicate Slag Inclusions G.M. ↑ C G.M. ↑ D, except that stringers are fragmented

← G.M. Type A shows scattered small inclusions →

G.M. ↑ B G.M. ↑ C Oxide Inclusions G.M. ↑ D

Method for Identification of Inclusions in Iron and Steel

Originated by Wm. Campbell and G. F. Comstock (Proc. A.S.T.M., Vol. 23, p. 521) and Modified by C. R. Wohrman, Merrill Scheil and Miss M. Baeyertz


Polish Specimen Carefully so as to Preserve Inclusions and Project Magnified Image on Ground Glass by Arc or Equally White Light Without Color Screen
Gray or Black Inclusions
Inclusions of Warm Colors
Etch 10 sec. with 10% nitric acid in alcohol
Etch 10 min. with boiling alkaline sodium picrate
Attacked IRON SULPHIDE (pale yellowish)
Unattacked
Strongly Attacked LIME COMPOUND from mold wash (rare)
Unattacked Etch 5 min. with 10% chromic acid in water (Be careful to observe that the polished surface is wetted by the solution)
Etch 10 min. in 20% aqueous solution of HF
Attacked: Removes ZIRCONIUM NITRIDE (yellow cubes) and ZIRCONIUM SULPHIDE (tan crystals)
Unattacked Inclusions in high chromium steels
Weakly Attacked (slightly pitted or darkened) COMPOUND OXIDE: (a) either FeO with FeS in solution (usually accompanied by FeO-FeS EUTECTIC), or (b) FeO+MnO and other OXIDES in solution
Note 1: Octahedral crystals are probably MAGNETITE.
Note 2: Both (a) and (b) will be darkened further by 20 sec. sulphur printing (2% H_2SO_4 in water) and destroyed by etching with stannous chloride as indicated below
Etch 5 min. in boiling 10% H_2SO_4 + 1% $KMnO_4$, & lightly repolish*
Unattacked CHROMIUM OXIDE (purplish gray by reflected light, bright green by transmitted light) TITANIUM NITRIDE (yellow cubes) TITANIUM CYANO-NITRIDE (pinkish; strongly angular, easily pitted in polishing)
Attacked CHROMITE $Cr_2O_3 \cdot FeO$, isotropic; red to brown by transmitted light
Attacked FeS-MnS, rich in MnS. Note: Reaction not always decisive. Any unattacked FeS-MnS will be blackened by next treatment
Unattacked Note color: (1) Very faint pale gray, (2) Medium or dark gray, and etch 5 min. with boiling alkaline sodium picrate
Completely Blackened (1*) FeS-MnS, MnS below 50% (2*) FeS-MnS, MnS above 50% or OXIDE very rich in MnO
* Refer to color before etch
Partly Attacked (a) OXIDE rich in MnO (will be destroyed by stannous chloride) (b) SILICATE with some MnO (will be destroyed by hydrofluoric acid)
Unattacked (or partly attacked in previous treatments) etch 10 min. with a saturated solution of stannous chloride in alcohol
Attacked IRON OXIDE or (if previously pitted) COMPOUND OXIDE
Unattacked (or previously pitted) etch 10 min. with 20% aqueous solution of hydrofluoric acid.
Attacked SILICATE (if previously pitted presence of Mn is indicated)
Unattacked Repolish and note color and form
If fine particles, very dark color, difficult to polish without pitting and not elongated by hot work is ALUMINA
If color not especially dark, easily polished smooth without pitting
Fairly large angular fragments, showing changeable bright spots as focus is changed, are SAND GRAINS (in steel castings)
Small angular particles, bluish in color probably TITANIUM OXIDE (in titanium treated steels)

* Note: Suitable only for stainless steels with clean (unoxidized) surfaces.

Supplementary Tests

In all instances check determinations in the light of the evidence of a careful chemical analysis, and, whenever possible, by other methods, such as:

I Sulphur Printing

(for 20 sec. using a 2% aqueous solution of H_2SO_4)
(1) Dissolves all FeS-MnS inclusions
(2) Partly dissolves (pits) FeO containing FeS and OXIDES of other metals in solution
(3) Leaves unchanged: IRON SULPHIDE (pale yellow), pure IRON OXIDE (medium gray), SILICATES (dark grey)

II Matweieff's Tests

(a) Dilute tartaric acid does not attack OXIDES or SILICATES, but colors MnS lightly and FeS decidedly
(b) Heat sample in hydrogen at 1600°F. OXIDES are reduced, SILICATES and SULPHIDES are unaffected
(c) Repolish (b), etch with dilute $FeCl_3$ in alcohol; if reduced oxide particles are colored deeply they contain some Mn

III Rohl's Test for Sulphides

Short etch with 1% picric acid in alcohol, then temper to dark yellow. FeS turns dark blue to reddish violet, and MnS turns dull grey to bright white.

It is not at all unusual, when treating the medium carbon low alloy types of steel with these potent alloy combinations, to show a Brinell hardness of 500 or more when oil quenched in relatively small sections which develop tensile strength exceeding 250,000 psi. in combination with a 50% reduction of area.

It is interesting to note that the latter addition is apparently only slightly effective in eutectoid compositions — that is, where you do not have present any boundaries of free ferrite in the slowly cooled steel. The addition also decreases in importance as the carbon drops below 0.30% and as the draw temperature increases above 1000° F., so that it is primarily useful for medium carbon steels. A specific example for T-1340 steel is given in Table I.

Several of these potent alloy combinations are now available and enough tests have been made of various steel analyses, to which they have been added in the ladle, so that we can state definitely that they are extremely powerful in improving the hardenability. This is true not only of the alloy steels but also the plain carbon steels. The results of fatigue testing especially are surprising for water quenched parts. It is quite certain that the knowledge we have gained will be helpful in building up properties in the low alloy steels (and perhaps in the carbon steels) which at the present time would seem somewhat fantastic. Table I and Fig. 2 show the effect of these special alloy additions on the physical properties and the hardenability of the quenched part as compared to ordinary steel.

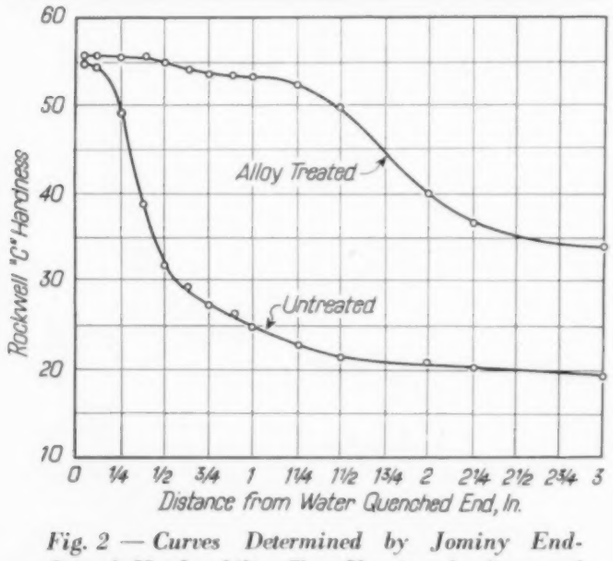


Fig. 2 — Curves Determined by Jominy End-Quench Hardenability Test Showing the Increased Depth of Hardening of S.A.E. T-1335 After Ladle Treatment With Special Alloy Combination

It is believed that such special alloy additions will find their widest application in the low alloy, medium carbon steels which are to be oil quenched. As mentioned above, they are apparently most effective in carbon ranges from 0.20 to 0.45%. This might be due to the fact that in this range any boundary ferrite remaining in the quenched and drawn structure is most effective in reducing ductility. (It is possible that, by balancing the carbon, the alloy content and the quenching speed, similar results can be approached without recourse to the special additions.) These additions are most effective only when used in conjunction with certain melting practices, and the steel making practice and alloy addition must be correctly related. The alloy additions are at present, at least, expensive enough to increase the cost of the steel appreciably, and consideration must be given to this side of the picture.

How widespread this development will become depends on the progress that is made in bringing our heat treating practice and steel selection up to the point where we are applying fully in practice the knowledge we have developed in our hardenability and transformation studies. I believe that many of our standard grades are not processed now to develop their heat treated properties to the full extent.

Free Ferrite at Grain Boundaries

So far as I have been able to determine, the primary reason for these interesting results lies in the fact that the combination which will produce the maximum ductility at high hardness is one in which the structure, be it tempered or untempered martensite, is uniformly free from boundary transformation products — especially ferrite. Thus, it is my opinion that for maximum properties at high hardness we should heat long and high enough for a high degree of chemical uniformity in the austenitic solid solution, and then quench fast enough so that excess ferrite does not have time enough to migrate and mass along the prior austenite grain boundaries. This means that the heating and quenching process should be worked out in practice to insure a quenched structure particularly free from any trace of boundary ferrite. Any attempt

(Continued on page 462)

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Analyses of S.A.E. Steels

Lines printed in italic represent secondary steels

Numerical designations and analyses of steels as delivered; list revised in 1941 by the Society of Automotive Engineers

Carbon Steels

S.A.E. No.	Carbon Range	Manganese Range	Phosphorus Max.	Sulphur Max.
1010	0.05-0.15	0.30-0.60	0.045	0.055
1015	0.10-0.20	0.30-0.60	0.045	0.055
X1015	0.10-0.20	0.70-1.00	0.045	0.055
1020	0.15-0.25	0.30-0.60	0.045	0.055
X1020	0.15-0.25	0.70-1.00	0.045	0.055
1025	0.20-0.30	0.30-0.60	0.045	0.055
X1025	*0.20-0.30*	*0.70-1.00*	*0.045*	*0.055*
1030	0.25-0.35	0.60-0.90	0.045	0.055
1035	0.30-0.40	0.60-0.90	0.045	0.055
1040	0.35-0.45	0.60-0.90	0.045	0.055
1045	0.40-0.50	0.60-0.90	0.045	0.055
1050	0.45-0.55	0.60-0.90	0.045	0.055
1055	0.50-0.60	0.60-0.90	0.040	0.055
1060	0.55-0.70	0.60-0.90	0.040	0.055
1065	*0.60-0.75*	*0.60-0.90*	*0.040*	*0.055*
X1065	*0.60-0.75*	*0.90-1.20*	*0.040*	*0.055*
1070	0.65-0.80	0.60-0.90	0.040	0.055
1075	0.70-0.85	0.60-0.90	0.040	0.055
1080	0.75-0.90	0.60-0.90	0.040	0.055
1085	0.80-0.95	0.60-0.90	0.040	0.055
1090	0.85-1.00	0.60-0.90	0.040	0.055
1095	0.90-1.05	0.25-0.50	0.040	0.055

Free Cutting Steels

S.A.E. No.	Carbon Range	Manganese Range	Phosphorus Range	Sulphur Range
1112	0.08-0.16	0.60-0.90	0.09-0.13	0.10-0.20
X1112	0.08-0.16	0.60-0.90	0.09-0.13	0.20-0.30
1115	0.10-0.20	0.70-1.00	0.045 max.	0.10-0.20
X1314	0.10-0.20	1.00-1.30	0.045 max.	0.10-0.20
X1315	0.10-0.20	1.30-1.60	0.045 max.	0.10-0.20
X1330	0.25-0.35	1.35-1.65	0.045 max.	0.10-0.20
X1335	0.30-0.40	1.35-1.65	0.045 max.	0.10-0.20
X1340	0.35-0.45	1.35-1.65	0.045 max.	0.10-0.20

Manganese Steels

See Note (a) for Silicon Content

No.	Carbon	Manganese	Phosphorus	Sulphur
1330	0.25-0.35	1.60-1.90	0.040 max.	0.050 max.
1335	0.30-0.40	1.60-1.90	0.040 max.	0.050 max.
1340	0.35-0.45	1.60-1.90	0.040 max.	0.050 max.
1350	*0.45-0.55*	*1.60-1.90*	*0.040 max.*	*0.050 max.*

Nickel Steels

See Notes (a) and (b) for Silicon, Phosphorus and Sulphur Content

No.	Carbon	Manganese	Nickel
2315	0.10-0.20	0.30-0.60	3.25-3.75
2330	0.25-0.35	0.50-0.80	3.25-3.75
2340	0.35-0.45	0.60-0.90	3.25-3.75
2345	0.40-0.50	0.60-0.90	3.25-3.75
2515	*0.10-0.20*	*0.30-0.60*	*4.75-5.25*

Nickel-Chromium Steels

See Notes (a) and (b) for Silicon, Phosphorus and Sulphur Content

No.	Carbon	Manganese	Nickel	Chromium
3115	*0.10-0.20*	*0.30-0.60*	*1.00-1.50*	*0.45-0.75*
3120	0.15-0.25	0.50-0.80	1.00-1.50	0.45-0.75
3130	*0.25-0.35*	*0.50-0.80*	*1.00-1.50*	*0.45-0.75*
3135	0.30-0.40	0.50-0.80	1.00-1.50	0.45-0.75
3140	0.35-0.45	0.60-0.90	1.00-1.50	0.45-0.75
X3140	0.35-0.45	0.60-0.90	1.00-1.50	0.60-0.90
3145	0.40-0.50	0.60-0.90	1.00-1.50	0.45-0.75
3150	0.45-0.55	0.60-0.90	1.00-1.50	0.45-0.75
3215	*0.10-0.20*	*0.30-0.60*	*1.50-2.00*	*0.90-1.25*
3220	*0.15-0.25*	*0.30-0.60*	*1.50-2.00*	*0.90-1.25*
3240	*0.35-0.45*	*0.30-0.60*	*1.50-2.00*	*0.90-1.25*
3245	*0.40-0.50*	*0.30-0.60*	*1.50-2.00*	*0.90-1.25*
3250	*0.45-0.55*	*0.30-0.60*	*1.50-2.00*	*0.90-1.25*
3312	max. 0.17	0.30-0.60	3.25-3.75	1.25-1.75
3415	*0.10-0.20*	*0.30-0.60*	*2.75-3.25*	*0.60-0.95*

Molybdenum Steels

See Notes (a) and (b) for Silicon, Phosphorus and Sulphur Content

S.A.E. No.	Carbon	Manganese	Chromium	Nickel	Molybdenum
X4130	0.25-0.35	0.40-0.60	0.80-1.10	.....	0.15-0.25
4140	0.35-0.45	0.60-0.90	0.80-1.10	.....	0.15-0.25
4150	0.45-0.55	0.60-0.90	0.80-1.10	.....	0.15-0.25
4320	0.15-0.25	0.40-0.70	0.30-0.60	1.65-2.00	0.20-0.30
X4340	0.35-0.45	0.60-0.90	0.60-0.90	1.65-2.00	0.20-0.30
4615	0.10-0.20	0.40-0.70	.....	1.65-2.00	0.20-0.30
4620	0.15-0.25	0.40-0.70	.....	1.65-2.00	0.20-0.30
4640	0.35-0.45	0.50-0.80	.....	1.65-2.00	0.20-0.30
4815	0.10-0.20	0.40-0.60	.....	3.25-3.75	0.20-0.30
4820	0.15-0.25	0.40-0.60	.....	3.25-3.75	0.20-0.30

Chromium Steels

See Note (a) for Silicon Content

S.A.E. No.	Carbon Range	Manganese Range	Phosphorus Max.	Sulphur Max.	Chromium Range
5120	0.15-0.25	0.60-0.90	0.040	0.050	0.60-0.90
5140	0.35-0.45	0.60-0.90	0.040	0.050	0.80-1.10
5150	0.45-0.55	0.60-0.90	0.040	0.050	0.80-1.10
52100	0.95-1.10	0.20-0.50	0.030	0.035	1.20-1.50

Chromium-Vanadium Steels

See Notes (a) and (b) for Silicon, Phosphorus and Sulphur

S.A.E. No.	Carbon Range	Manganese Range	Chromium Range	Vanadium Minimum	Vanadium Desired
6135	*0.30-0.40*	*0.60-0.90*	*0.80-1.10*	*0.15*	*0.18*
6150	0.45-0.55	0.60-0.90	0.80-1.10	0.15	0.18

Silicon-Manganese Steels

See Note (b) for Phosphorus and Sulphur

No.	Carbon	Manganese	Silicon
9250	0.45-0.55	0.60-0.90	1.80-2.20
9260	0.55-0.65	0.60-0.90	1.80-2.20

Chromium-Nickel Austenitic Steels

See Note (c) for Phosphorus and Sulphur

No.	Carbon	Manganese	Silicon Max.	Chromium	Nickel	Molybdenum
30615 (Type 1)	0.15 max.	2.00 max.	0.75	17.00-20.00	7.00-10.00	0.60 max.
30615 (Type 2)	0.15 max.	2.00 max.	0.75	17.00-20.00*	7.00-10.00	0.60 max.
30705	0.08 max.	2.50 max.	1.50	17.00 min.†	8.00 min.	.....
30805	0.10 max.	2.50 max.	0.75	16.00-18.00	10.00-14.00	2.00-3.00
30905	0.08 max.	2.00 max.	0.75	18.00-20.00	8.00-10.00	.....
30915	0.08-0.15	2.00 max.	0.75	17.00-20.00	7.00-10.00	.....

*Contains also 0.15-0.35% selenium.
†Contains 0.40% min. titanium or 0.70% min. columbium.

Stainless Chromium-Irons

See Note (d) for Phosphorus and Sulphur

No.	Carbon	Manganese	Silicon Max.	Chromium	Nickel	Molybdenum
51210	0.08-0.15	0.60 max.	0.50	11.50-13.00	.....	.....
51310	0.08-0.15	0.60 max.	0.50	11.50-13.00	1.25-2.00	.....
51335	0.25-0.40	0.60 max.	0.50	12.00-14.00	.....	.....
X51410	0.13 max.	1.20 max.	0.75	12.00-14.00	.....	0.60 max.
51710	0.12 max.	0.60 max.	0.50	16.00-18.00	.....	.....

Notes to Tables of Chemical Composition

Note (a). Silicon range of all S.A.E. basic openhearth alloy steels shall be 0.15 to 0.30%. For electric furnace alloy steels and acid openhearth alloy steels, the silicon content shall be 0.15% minimum.

Note (b). Phosphorus and sulphur in all S.A.E. nickel steels, nickel-chromium steels, molybdenum steels, chromium-vanadium steels and silicon-manganese steels shall be 0.040% max. and 0.050% max. respectively.

Note (c). Phosphorus in 30615 Type 1 is 0.04% max., in Type 2 is 0.12 to 0.17%; in the other alloys is 0.03% max. Sulphur in 30615 Type 1 is 0.18 to 0.35%, in Type 2 is 0.04% max.; in the other alloys is 0.03% max.

Note (d). Phosphorus and sulphur in all the chromium-irons except X51410 shall be 0.03% max. each. In X51410 phosphorus shall be 0.04% max.; sulphur shall be 0.18-0.35%.

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Toolsteels Classified by Wear-Toughness Ratio

By Harold B. Chambers (See Metal Progress, June 1940, for Its Use as a Tool Selector)

Each of the three groups arranged in order of increasing toughness and decreasing wear resistance. Figures indicated as max. are optional and may be present up to amount noted. Since the difference in relative wear-toughness capacities of adjacent classes is small to negligible, the many brands covered by each class may be expected to give competitive performance except when highly standardized operating conditions require that consideration be given to the footnotes.

Class	Conventional Type Names	Carbon	Manganese	Silicon	Tungsten	Chromium	Vanadium	Molybdenum	Cobalt	Nickel	Notes
	Water Hardening Steels										
1A	Tungsten finishing	1.25-1.50	0.15-0.35	0.15-0.50	2.50- 6.00	1.80 max.	0.30 max.	0.50 max.			A,B,C
1B	Carbon or carbon-vanadium	1.30-1.45	0.15-0.35	0.15-0.35		0.35 max.	0.30 max.				A,C
2A	High carbon, low tungsten	1.10-1.30	0.15-0.35	0.15-0.35	1.00- 2.50	0.35 max.	0.30 max.				A,B
2B	Low chromium or chrome-vanadium	1.10-1.30	0.15-0.35	0.15-0.35		0.10- 1.20	0.30 max.				A,C
2C	Carbon or carbon-vanadium	1.10-1.30	0.15-0.35	0.15-0.35			0.30 max.				A
3A	High carbon, low tungsten	0.90-1.10	0.15-0.35	0.15-0.35	1.00- 2.50	0.75 max.	0.30 max.				A,B,C
3B	Low chromium or chrome-vanadium	0.90-1.10	0.15-0.35	0.15-0.35		0.10- 1.50	0.30 max.				A,C
3C	Carbon or carbon-vanadium	0.90-1.10	0.15-0.35	0.15-0.50			0.50 max.				A,D
4A	Chrome-molybdenum or chrome-vanadium	0.55-0.90	0.15-0.35	0.15-0.35		0.40- 1.20	0.35 max.	0.25 max.		0.50 max.	A,C
4B	Carbon or carbon-vanadium	0.70-0.90	0.15-0.35	0.15-0.35			0.30 max.				A
4C	Silico-manganese or silico-molybdenum	0.45-0.75	0.35-1.00	0.75-2.25		0.60 max.	0.35 max.	0.60 max.			A,E
	Oil Hardening and Air Hardening Steels (Tools of Intricate Design)										
5A	High carbon, high chromium	1.80-2.50	0.15-1.20	0.15-1.00	2.00 max.	10.50-14.00	1.25 max.	0.30 max.	1.00 max.	1.00 max.	A,F,G
5B	High carbon, high chromium	1.80-2.40	0.15-0.60	0.15-0.50		10.50-14.00	1.20 max.	0.70- 1.00	0.60 max.		A,F,G
5C	High carbon, high chromium	1.30-1.70	0.15-0.60	0.15-0.50		10.50-14.00	1.20 max.	0.50- 1.25	4.00 max.	1.00 max.	A,F,G
5D	High carbon, high chromium	1.10-1.40	0.15-1.20	0.15-1.10		5.00-13.00	0.75 max.	0.70- 1.50	0.60 max.		A,F,G
6A	Chrome-molybdenum	1.10-1.30	0.35-0.95	0.15-0.35		0.40- 1.75		0.25- 0.75			A,E
6B	High carbon, low tungsten	1.10-1.30	0.15-0.70	0.15-0.35	1.00- 2.50	0.35- 1.25	0.30 max.				A,B,C
6C	Low chromium or chrome-vanadium	1.10-1.30	0.35-0.70	0.15-0.35		0.40- 1.50	0.30 max.				A,C
7A	Cr-Mo, Mn-Cr, or Mn-Mo non-deforming	0.90-1.10	0.35-3.00	0.15-1.00		0.80- 5.50	0.50 max.	0.80-1.75			A,E
7B	Chromium non-deforming	0.90-1.10	0.35-1.10	0.15-0.50	1.10 max.	0.90- 1.60	0.30 max.	0.50 max.			A,E
7C	Manganese non-deforming	0.80-1.10	0.85-1.80	0.15-0.50	0.70 max.	0.90 max.	0.30 max.	0.35 max.			A,E
8A	Low tungsten-chromium	0.40-0.65	0.15-0.35	0.15-1.50	0.75- 3.00	0.50- 2.00	0.50 max.	0.35 max.		1.50 max.	A,E
8B	Chrome-nickel or chrome-nickel-molybdenum	0.50-0.80	0.35-0.90	0.15-0.35		0.50- 1.25	0.30 max.	0.80 max.		1.00-2.50	A,E
8C	Chrome-molybdenum, chrome-vanadium, or manganese-molybdenum	0.50-0.90	0.35-0.90	0.15-0.50		1.20 max.	0.35 max.	0.40 max.		0.50 max.	A,E
8D	Silico-molybdenum	0.45-0.60	0.35-1.25	0.75-2.25	0.50 max.	0.75 max.	0.60 max.	0.15- 2.20			A,E
	High Speed (H.S.) Steels and Hot Work (H.W.) Steels (Tools Which Heat Up)										
9A	Tungsten-cobalt high speed	0.70-0.90	0.15-0.35	0.15-0.35	18.00-23.00	3.50- 4.75	1.25-3.00	1.25 max.	9.00-15.00		A,G,H
9B	Tungsten-cobalt high speed	0.65-0.90	0.15-0.35	0.15-0.35	17.00-21.00	3.50- 4.75	1.00-2.50	1.25 max.	5.00- 9.00		A,G,H
9C	Tungsten-cobalt high speed	0.65-0.80	0.15-0.35	0.15-0.35	17.00-20.00	3.50- 4.75	0.75-1.50	1.00 max.	2.00- 5.00		A,G,H
9D	Tungsten-cobalt high speed	0.65-0.85	0.15-0.35	0.15-0.35	12.00-15.00	3.50- 4.75	1.25-2.25	0.75 max.	3.00- 8.00		A,G,H
9E*	Molybdenum-cobalt H.S.	0.75-0.90	0.15-0.35	0.15-0.35	6.50 max.	3.50- 4.75	1.00-2.50	6.00-10.00	2.00- 9.00		A,G,H
10A	18-4-4 and 18-4-3 high speed	0.90-1.30	0.15-0.35	0.15-0.50	17.00-19.00	3.50- 4.75	2.50-4.25	1.00 max.			A,H
10B	18-4-2 high speed	0.75-0.90	0.15-0.35	0.15-0.50	17.00-19.00	3.50- 4.75	1.50-2.50	1.00 max.			A,H
10C	18-4-1 high speed	0.55-0.80	0.15-0.35	0.15-0.75	16.00-21.00	3.50- 4.75	0.50-1.50				A,H
10D	14-4-2 and 14-4-1 high speed	0.55-0.80	0.15-0.35	0.15-0.35	13.00-15.00	3.50- 4.75	0.75-2.25				A,H
10E*	Mo-W or Mo-V high speed	0.65-1.30	0.15-0.35	0.15-0.50	6.50 max.	3.50- 4.75	0.75-4.25	3.50- 9.50			A,H
11A	Low carbon high speed	0.45-0.60	0.15-0.35	0.15-0.35	16.00-19.00	3.00- 4.50	0.50-1.25				A,H,I
11B	High tungsten hot work	0.25-0.60	0.15-0.35	0.15-0.35	12.00-16.00	2.50- 4.50	0.30-0.75	2.50 max.		3.00 max.	A,H,I
11C	Tungsten hot work	0.25-0.50	0.15-0.35	0.15-0.35	8.00-12.00	1.25- 3.50	0.60 max.	1.00 max.	2.00 max.	2.25 max.	A,H,I
11D*	Mo, or Mo-W hot work	0.30-0.65	0.15-0.35	0.15-1.75	3.00 max.	2.00- 5.50	0.30-1.25	2.50 -9.00		1.75 max.	A,H,I
11E	Tungsten-chromium H.W.	0.30-0.60	0.15-0.75	0.35-1.75	4.00- 7.50	4.50- 7.50	0.60 max.	1.00 max.	0.60 max.	0.50 max.	A,H,I
12A	Chrome-molybdenum H.W.	0.30-0.50	0.15-1.25	0.80-1.10	1.50 max.	4.00- 7.50	0.50 max.	0.45- 1.75	0.60 max.	1.75 max.	A,H
12B	Low tungsten-chromium H.W.	0.35-0.65	0.15-0.80	0.15-1.10	1.50- 4.25	0.75- 3.50	0.50 max.	0.60 max.		1.50 max.	A,H
12C	Chrome-molybdenum H.W. or chromium hot work	0.30-1.00	0.15-0.75	0.15-0.75	1.00 max.	2.25- 4.50	1.00 max.	1.00 max.		0.50 max.	A,H
12D	Cr-Ni, or Cr-Ni-Mo hot work	0.25-0.60	0.15-1.00	0.15-0.35		0.50- 2.50	0.30 max.	1.00 max.		1.25-5.00	A,H

A. Wear resistance increases and toughness decreases as carbon content increases.

B. Wear resistance increases and toughness decreases as tungsten content increases.

C. Hardenability increases, wear resistance increases, toughness decreases, movement in hardening decreases, and tendency for soft spots in hardening decreases as chromium increases.

D. Some special applications (silverware striking dies, certain header dies, etc.) may occasionally require extra penetration of hardness, which may be produced by adjusting manganese and silicon contents.

E. Hardenability increases, wear resistance increases and toughness decreases as total alloy content increases.

F. Machining difficulties increase as total alloy content increases.

G. Red hardness properties increase and toughness decreases as cobalt content increases.

H. Red hardness properties increase and toughness decreases as total alloy content increases.

I. Water cooling surface in operation, particularly when intermittent, tends to promote heat checking approximately in proportion to tungsten and/or molybdenum content.

*Not divided into classes. The relative position of a specific molybdenum steel is just below its tungsten steel counterpart. The tungsten counterpart is indicated by adding twice the molybdenum content to the tungsten in a molybdenum steel having 0.05-0.10% higher carbon than the tungsten steel.

to obtain the *maximum* combination of properties in heat treated (that is, quenched and drawn) steel must be based upon a fully hardened structure as quenched, and therefore the analysis, hardenability and equipment must be adjusted to produce this type of structure.

Wherever the microstructure combines martensitic grains or tempered martensitic grains with ferrite boundaries we will find that, when the specimen is subjected to tension, the stress will tend to be thrown by the stiff unyielding grains into the softer ferrite boundaries and there concentrated. While relatively very ductile, the ferrite has a low strength; the stress concentrations reduce greatly the overall ductility of the piece being tested. If the structure is homogeneous the stress will be more evenly distributed throughout the entire length and width of the test piece and the reduction of area will be a maximum.

The question of homogeneity in the microstructure is, of course, tied up with the time and temperature of the heating cycle as well as the grain size and carbon content. "Homogeneous martensite" implies that sufficient time and temperature has been given to permit carbon to diffuse throughout the ferrite boundaries in the the annealed or as-rolled hypo-eutectoid steels, and this means not only the boundaries of the austenitic grain but also those much larger grain boundaries which mark the original dendritic crystals in the ingot. It has been demonstrated that such boundaries exist in practically all fine-grained hypo-eutectoid steels and they can be revealed by slowly etching the quenched and drawn structure (if the time and temperature of the heating cycle has been insufficient to insure complete diffusion of the carbon across such boundaries).

According to McBride, Herty and Mehl, in their paper in *Transactions* ⊕ Vol. 24 (1936) p. 281, entitled "The Effect of Deoxidation on the Rate of Formation of Ferrite in Commercial Steels", the deoxidation method for openhearth steel has a direct effect on the tendency to form pro-eutectoid ferrite on cooling below the critical range. The *rate* of precipitation of ferrite in austenite on cooling varies with the degree of undercool and the deoxidation practice. This variation is more marked in silicon killed steels than in aluminum killed steels, and, according to these investigators, the reason is not clear. At low degrees of undercool the rate of ferrite precipitation is greater in aluminum killed steels than in silicon killed, while at greater degrees of undercool the reverse is true.

Thus, the type of deoxidation practice might affect the tendency to produce a martensite with boundary ferrite, and the amount of pro-eutectoid ferrite might be less in the aluminum killed types of steel after quenching.

Fig. 3 — Martensite at 750 Diameters, Free From Boundary Ferrite. S.A.E. X-1020 plus 0.25% chromium, quenched in water

While it may follow that the best combination of ductility and strength at high hardness is obtained by starting with the most homogeneous austenite, transformed into the most homogeneous martensite free from transition microstructures, it should also follow that the best combination at lower hardnesses would be obtained by tempering this martensite to produce uniformly fine sorbitic structures free from boundary ferrite. This, of course, is true — providing the homogeneous martensitic structure is free from high internal stresses and ruptures which occur when cooling is continued to temperatures much below 300° F.

Use of "S" Curves

It is apparent that if we are to cool the heated work so as to obtain a completely homogeneous martensitic structure throughout it will be necessary to know — for any given piece of steel — the time available before transformation starts at any temperature. This will vary with analysis and grain size, and the structures which will be obtained from a given section can be easily determined by a few quenching experiments. The cooling curves of various sections can be determined in the usual manner and

plotted on the same chart as a curve showing the time required for the transformation to start at any given temperature. Such curves have been very carefully worked out (two of them are given in detail on pages 516 and 517 of this issue).

One of the most informative contributions in recent years to our study of steel has been the original development of these "S" curves by BAIN and DAVENPORT ("Transformation of Austenite at Constant Sub-Critical Temperatures," *Transactions* A.I.M.E., 1930). Their studies have clarified the time-temperature effects at various rates of cooling on steels of

obtained on quenching hypo-eutectoid steels from *within* the critical range on heating will result in poor ductility. That a similar type of structure, obtained by relatively slow cooling during quenching *through* the range of temperature where the austenite and ferrite are both stable, is also conducive to lowered ductility has not been so well known. When this fact is better appreciated, much more attention will be given to avoiding pro-eutectoid ferrite at the grain boundaries of quenched and drawn work.

The "S" curve is similar, in a general way, for most of the engineering types of alloy steels in that the transformation from the gamma

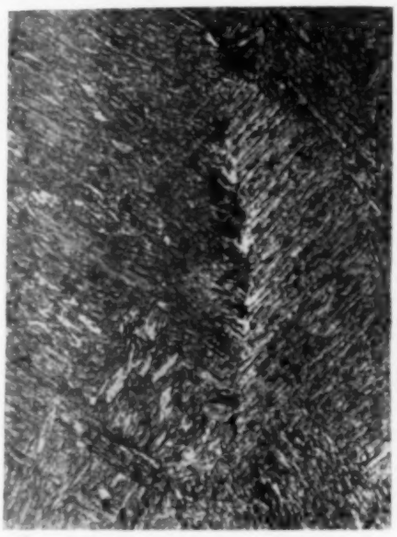


Fig. 4—Fastest cooling rate

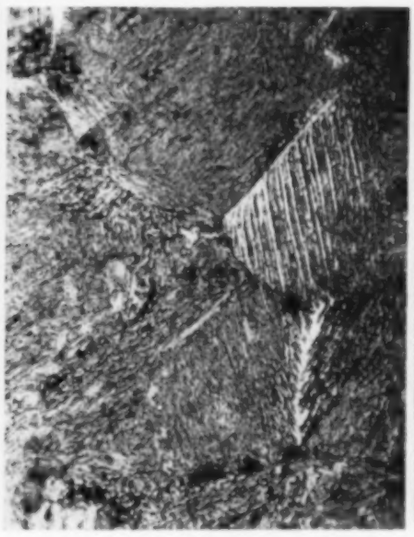


Fig. 5—Slower cool; some ferrite

Fig. 6—Slowest; ferrite network

Microstructures Showing Increasing Amounts of Boundary Ferrite, All at 1000 Diameters

various compositions. The "S" curve provides us with a means of knowing the time and temperature at which a given steel will start to transform when cooling and the structures which would be obtained if complete transformation were permitted at any given temperature.

A great deal has been written about the decomposition of austenite, and very elaborate and complete studies have been made of the products of this decomposition. However, until the development of the "S" curves there was little published about the actual beginning of the austenite → ferrite transformation. Even less has been published on the effect of undissolved ferrite on the properties of the quenched and drawn work. It is quite commonly assumed that the mixture of martensite and ferrite

to the alpha phase occurs most quickly at a temperature of approximately 1000° F. and results in fine pearlite. At temperatures above or below this point the time required for the transformation *to start* is greatly increased. Thus, we find that at approximately 1000° F. the upper bend of the "S" curve denoting "beginning of transformation" approaches the line of zero time most closely, so that a "neck" or "gate" is set up which limits the time available in which the piece can be cooled past that temperature without transformation to fine pearlite. This is of course necessary if a 100% martensitic structure is desired.

In general, the effect of alloy addition is to widen this "gate" so that longer (slower) cooling times are possible. For instance, the curve on page 516 shows that a 0.78% carbon steel

Specific Effects of Alloys in Steel

Element	Solubility		Influence Exerted Through Carbides			Influence on Ferrite	Principal Functions
	In Gamma Iron	In Alpha Iron	Carbide Forming Tendency	Effect on Hardenability	Action During Tempering		
Aluminum Al	1.1% (Increased by C)	30% ±	Less than Fe (Graphitizes)	Mildly positive (If any dissolved in austenite)	.....	Hardens considerably by solid solution	1. Deoxidizes efficiently 2. Restricts grain growth (by forming dispersed oxides or nitrides) 3. Alloying element in nitriding steel
Chromium Cr	12.8% (20% with 0.5% C)	Unlimited	Greater than Mn Less than W	Moderate (Up to 1% more effective than Mn)	Mildly resists softening	Hardens slightly (increases corrosion resistance)	1. Increases corrosion and oxidation resistance 2. Increases hardenability 3. Contributes some strength at high temperatures 4. Resists abrasion and wear (with high carbon)
Cobalt Co	Unlimited	80% ±	Similar to Fe	Negative (That is, decreases it)	Sustains hardness by solid solution	Hardens by solid solution	1. Contributes to red hardness by hardening ferrite
Manganese Mn	Unlimited	15 to 18%	Greater than Fe Less than Cr	Moderate (Ni < Mn < Cr) Retains austenite	Very little, in usual percentages	Hardens markedly and reduces plasticity	1. Counteracts embrittlement by inevitable sulphur 2. Increases hardenability inexpensively 3. Forms batter resistant steel (high Mn, high C)
Molybdenum Mo	3% ± (8% with 0.30% C)	32% (Less with lower temperatures)	Strong Greater than Cr	Great (When dissolved) Mo > Cr	Opposes softening by a secondary hardening	Gives age hardening systems in high Mo-Fe alloys	1. Raises coarsening temperature of austenite 2. Deepens hardening 3. Raises hot strength, creep resistance and red hardness 4. Enhances corrosion resistance in stainless
Nickel Ni	Unlimited	25% ± (Irrespective of carbon content)	Less than Fe (Graphitizes)	Mild Retains austenite in medium carbon steels	Very little in small percentages	Strengthens and toughens by solid solution	1. Strengthens unquenched or annealed steels 2. Toughens pearlitic-ferritic steels (especially at low temperature) 3. Renders high chromium-iron alloys austenitic
Phosphorus P	0.5%	2.5% (Irrespective of carbon content)	Nil	.....	.....	Effective hardener by solid solution effect	1. Strengthens low carbon steel 2. Increases resistance to corrosion 3. Improves machinability in free-cutting steels
Silicon Si	2% ± (9% with 0.35% C)	18.5% (Even with considerable carbon)	Negative (Graphitizes)	Moderate	Sustains hardness by solid solution	Hardens with loss in plasticity Mn < Si < P	1. Used as general purpose deoxidizer 2. Alloy for electrical and magnetic sheet 3. Improves oxidation resistance 4. Increases hardenability of steels carrying non-graphitizing elements 5. Strengthens low alloy steels
Titanium Ti	0.75% (1% with 0.20% C)	6% ± (Less with lower temperatures)	Maximum (2% Ti renders 0.50% carbon steel unhardenable)	Strong, if dissolved (Persistent carbides restrain grain growth and withhold carbon; therefore reduce hardenability)	Persistent carbides probably unaffected	Age hardening systems in high Ti-Fe alloys	1. Fixes carbon in inert particles (a) Reduces martensitic hardness and hardenability in medium chromium steels (b) Prevents formation of austenite in high chromium steels (c) Prevents localized depletion of chromium in stainless steels during long heating
Tungsten W	6% ± (11% with 0.25% C)	32% (Less with lower temperatures)	Strong	Considerable, especially in small percentages	Opposes softening by secondary hardening	Age hardening systems in high W-Fe alloys	1. Forms hard, abrasion resistant particles in toolsteels 2. Promotes red hardness and hot strength
Vanadium V	1 to 2% (4% with 0.20% C)	Unlimited	Very strong V < Ti or Cb	Marked (When dissolved)	Maximum for secondary hardening	Hardens moderately by solid solution	1. Elevates coarsening temperature of austenite (promotes fine grain) 2. Increases hardenability (when dissolved) 3. Resists tempering 4. Gives marked secondary hardening

Adapted from "The Functions of the Alloying Elements in Steel" by Edgar C. Bain; published by ASM

must be cooled to 950° F. in 1 sec. in order to avoid precipient transformation into fine pearlite (nodular troostite), whereas the "S" curve for S.A.E. 4140 (page 517) shows that austenite is completely retained if the hot homogeneous steel is cooled past 900° F. in 2½ sec. It is necessary therefore that if we are to have a completely martensitic structure, there will have to be a balance between the alloy content and the rate of cooling. (Carbon is also very effective in increasing the time available in getting through the "gate", so that from the viewpoint of improved quenched structures the higher carbon steels are desirable.)

It is of course obvious that it is possible to arrive at the same time-temperature point on the "S" curve by various routes, one of which might be by a moderate but fairly uniform rate to say 600° F., and another by an extremely rapid rate of cooling to 600° F. and then holding at this temperature until the curve of slow cooling is intercepted. The structures obtained by these two methods of cooling will differ markedly.

The slower cooled piece will have some ferrite in the grain boundaries which, as mentioned above, serves to localize an applied stress and hence reduce the ductility as usually measured. The structure from the faster cool will consist of a uniform martensitic (acicular) structure free from the soft ferrite boundaries and hence will have a greater ability to distribute any applied stress equally. We should consider very carefully the effect of boundary ferrite (soft substance) especially when interspersed throughout grains of hard and unyielding martensite. Under such conditions the ferrite is not much better than an inclusion and, while relatively very ductile, its extremely low tensile strength prevents any beneficial effect from this ductility except perhaps under compression.

The "S" curve for an alloy steel — for instance S.A.E. 4140 on page 517 — shows a region where ferrite is the first product of decomposition of austenite, and if we plot the surface cooling curves for oil quenched parts of any appreciable size we will find that they pass through this area to a degree depending upon the size of the piece. In fact, it is difficult in many designs to avoid this unless a very considerable amount of alloy is added to the steel or a water quench is employed. This region is dependent to a large degree upon the carbon content and disappears entirely in a steel of eutectoid composition.

It is worthy of repetition that the combination of martensite and ferrite is a particularly poor one from the standpoint of ductility, whether it is developed by slow cooling or insufficient soaking time at the quenching heat.

The maximum effect of ferrite in the boundaries of a quenched steel on the ductility occurs when it is in combination with fully hardened martensitic grains. Here we have a mixture of grains of high hardness and strength combined with relatively thin boundaries which are weak and ductile. If the austenite grains had time at 1000° F. and above to transform to fine pearlite instead of martensite the effect of the ferrite in the boundaries would be greatly reduced, perhaps because of the manner in which the boundary ferrite and interlamellar ferrite divide the applied stresses.

Influence of Alloys in Steel

It must be remembered that the "S" curves represent transformations at constant temperature levels. Messrs. GRANGE and KIEFER have demonstrated (*Transactions* ASM March 1941, page 85) that the effect of temperature changes along an actual cooling curve during quenching would be to lower the temperature and increase the time at which transformation would start, so that the practical tendency is to produce a martensitic structure with more ferrite than would be anticipated by the curves of isothermal transformation. (See Fig. 9, page 467.)

A comparison of Fig. 7 representative of the nickel and manganese steels and Fig. 8 representative of the chromium, chromium-vanadium and chromium-molybdenum types (page 466) indicates regions of stability of ferrite above 1000° F. and reveals that the possibility of obtaining a martensite-ferrite structure is greater with the chromium steels. At time-temperature combinations corresponding to ordinary oil quenched parts of normal size, we find that the cooling curve at 1000° F. passes through the zone of maximum tendency to produce martensite-ferrite structure in the chromium steels. In the nickel and manganese types the tendency to form ferrite under the same condition is much less — the curves representing "beginning of ferrite precipitation" and "appearance of lamellar structure" are rapidly approaching each other — so the chances that no pro-eutectoid ferrite will appear in the boundaries should therefore improve. This is true even though the time available to obtain

Metal Progress, 1941 Reference Issue, Page 465

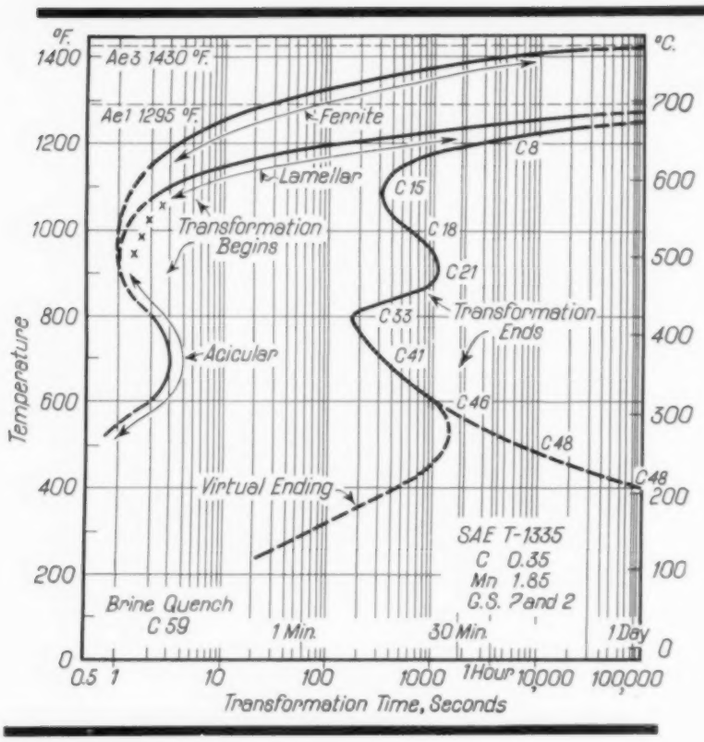


Fig. 7 — "S" Curves of Isothermal Transformation for Steel S.A.E. T-1335, Taken From E. S. Davenport's Campbell Memorial Lecture (1939). This is typical of the manganese and the nickel steels

a full martensitic structure is greater in the commercial chromium types, that is, the "gate" is somewhat wider. This suggests that these steels require a better quenching medium for proper microstructure, even though the specified hardness does not require it.

Naturally, the amount of pro-eutectoid ferrite which can appear at the boundaries of the quenched work depends on the closeness of the composition to the eutectoid, and this is affected not only by the carbon content but by the alloy content. Vanadium, manganese, chromium and molybdenum reduce the amount of carbon required for eutectoid compositions and, if they did not affect otherwise the austenite-ferrite field of the "S" curve, would tend to reduce the amount of boundary ferrite in the quenched work of a 0.50% carbon steel, for instance. Quenching studies show, however, that both vanadium and chromium would tend to increase rather than decrease the amount of ferrite in a structure obtained at about 1000° F. with commercial oil quenching as compared to manganese, nickel and molybdenum. It follows that, when oil quenched, manganese, nickel and molybdenum alloy steels at high hardness should give better combinations of ductility and strength than the chromium or vanadium types.

The structure in a given hypo-eutectoid steel (S.A.E. 4340 — 1.8% Ni, 0.8% Cr, 0.33% Mo) formed on cooling from above the critical range is noted at the bottom of Fig. 9 and can be divided into three principal types. These are *(a)* martensite, *(b)* martensite + ferrite, and *(c)* pearlite + ferrite. In addition to these three we may have some untransformed structure (austenite) resulting from extremely fast cooling or high alloy content, and some intermediate structures. These intermediate structures consist of various modifications of martensite (principal of which is the rapidly etching acicular structure bainite) together with martensite and ferrite, and also martensitic structures with pearlite and ferrite.

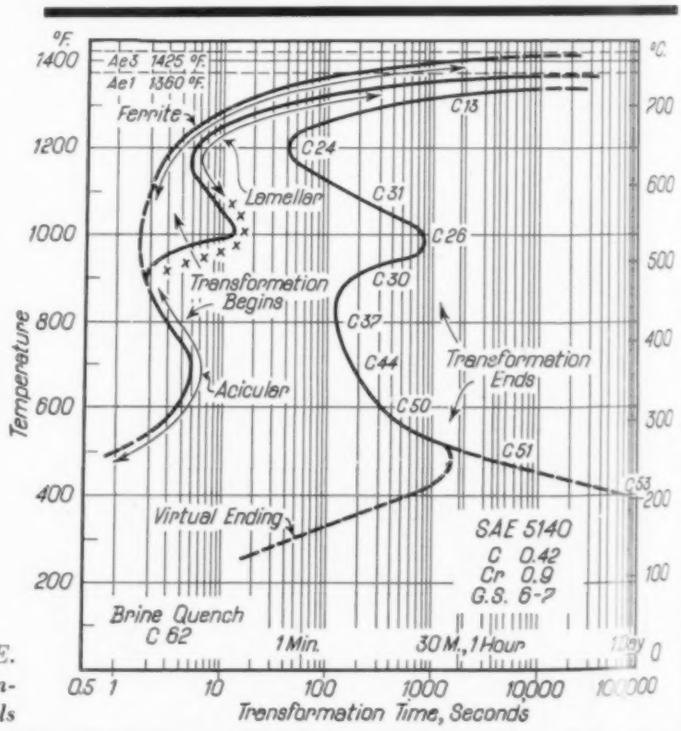


Fig. 8 — Davenport's "S" Curve for S.A.E. 5140, Typical of Chromium, Chromium-Vanadium & Chromium-Molybdenum Steels

The modified martensitic structures (bainite) without boundary ferrite possess excellent structural properties but the presence of proeutectoid ferrite is again distinctly detrimental.

The cooling rates which produce these structures vary with the grain size, and analysis of the steel — in short, its hardenability. In the high hardenability (deep hardening) steels the ranges are much wider and hence cover a very much greater cooling time. In the lower hardenability steels (shallow hardening) the ranges are much narrower, less distinct and cover a very narrow range of cooling time. If it is considered necessary to produce a specific quenched structure, therefore, in a low hardenability steel the limitation may be extreme and it may be necessary to resort to a combination time quenching.

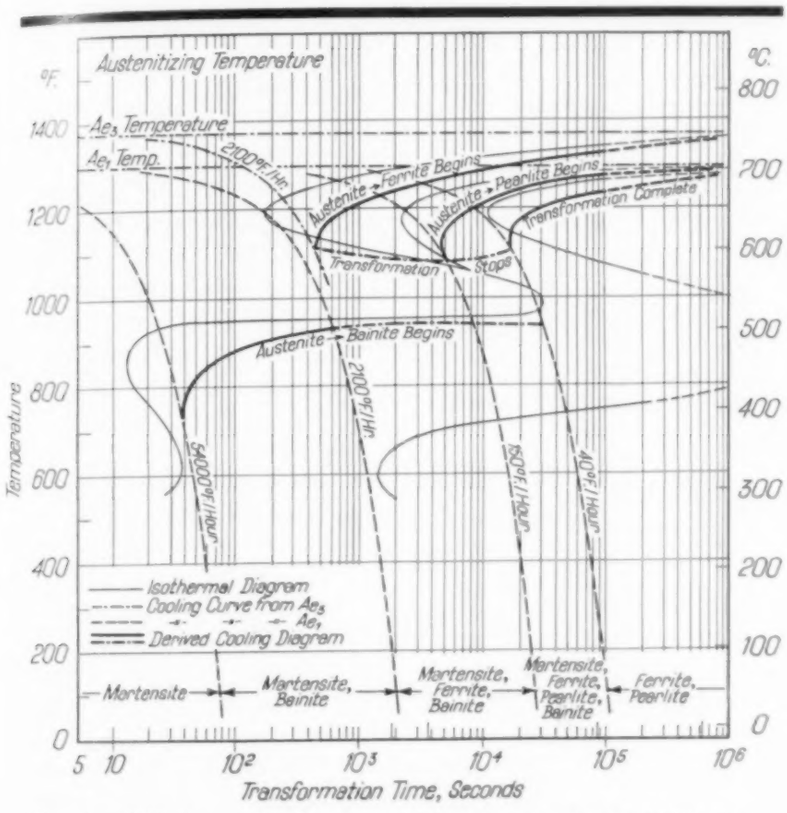


Fig. 9 — "S" Curves (as Shown in Light Lines for S.A.E. 4340) Are on the Basis of Instantaneous Cooling to a Certain Temperature and Holding Constant. Actual cooling of sub-surface regions, during commercial quenching, is at a more or less uniform rate — at least for the first stages. This causes the actual commencement and completion of the transformations to occur at slightly lower temperatures and considerably longer times. (Grange and Kiefer.) Ultimate micro-structures are noted in the line at the bottom of the sketch

There is a possibility that within certain limits the future may develop that the structure is the principal index of properties, and that no matter how obtained the desired goal may be a given quenched structure. It may be possible to disregard analysis specification and require only a steel which will produce a given structure when treated under the conditions of a given practice. This would make the hardenability test more important than the chemical analysis, and would center attention on heat treatments which would develop the desired structure in the simpler steels.

Actual Cooling Velocities

It is quite apparent that we must know the cooling rates imposed on a given piece of work as well as the quenching speeds required to produce homogeneous martensitic structure. The "S" curve itself is rather difficult to map and requires expensive and time consuming experiments. It also implies conditions of isothermal transformation that occur only when quenching in hot baths. It is possible to derive from "S" curves such diagrams as Fig. 9, showing the transformations during continuous cooling, as demonstrated by GRANGE and KIEFER in *Transactions* ASM March 1941, page 85, but it is rather difficult to determine the actual cooling rate in rapid quenches, or even in the air cooling of small pieces.

A more practicable way is to use one of the accepted hardenability tests, which has been calibrated against section to determine the reaction of a given steel to other cooling rates than the "critical cooling rate" and to determine the cooling rate in any part of a given piece.

In my opinion the simplest hardenability test which has been developed to date for such a purpose is the test proposed by WALTER E. JOMINY. This consists in taking a cylinder approximately 1 in. in diameter and 3 in. long, and heating it so that it presents a clean scale-

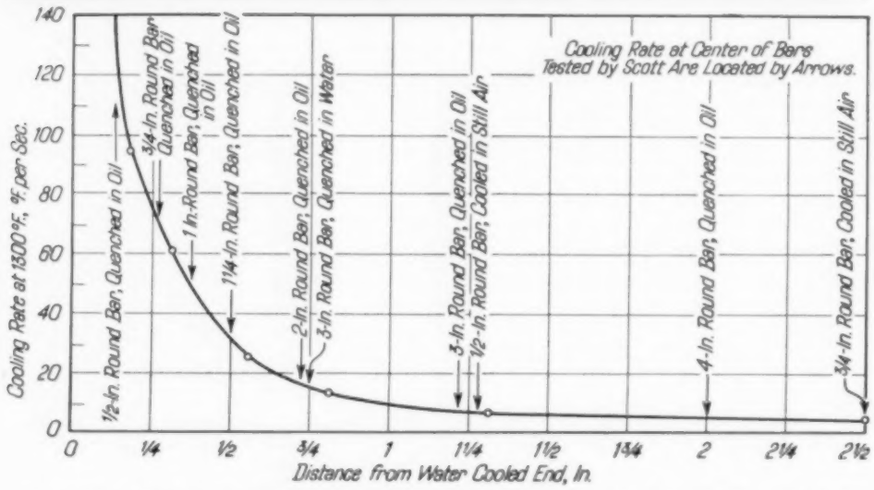

Cooling Rate at 1300°F., °F. per Sec.
Distance from Water Cooled End, In.
Cooling Rate at Center of Bars Tested by Scott Are Located by Arrows.
½-In. Round Bar, Quenched in Oil
¾-In. Round Bar, Quenched in Oil
1-In. Round Bar, Quenched in Oil
1¼-In. Round Bar, Quenched in Oil
2-In. Round Bar, Quenched in Oil
3-In. Round Bar, Quenched in Water
3-In. Round Bar, Quenched in Oil
½-In. Round Bar, Cooled in Still Air
4-In. Round Bar, Quenched in Oil
¾-In. Round Bar, Cooled in Still Air

Fig. 10— End-Quench Bar, 1 In. Diameter, of S.A.E. 1095 Steel Was Cooled From 1700° F. and Cooling Curves at the Surface Determined at Various Distances From the End. Rates of cooling at 1300° F. in ° F. per sec. were computed from these cooling curves and plotted in the above graph (Jominy)

free surface on the bottom end when quenched. This piece is heated in the same manner as the work it represents, and quenched with a jet of water against the clean scale-free end in such a manner that this end surface only is immediately brought down to the water temperature and maintained at this temperature until the rest of the piece has cooled to room temperature. The one end only receives the quenching spray, the rest of the piece is cooled by this end plus some cooling from the surrounding air.

We then have a quenched piece of steel of known analysis, heated according to a given cycle, and which has practically every cooling rate met in practice from the water quenched lower end to the slow cooled upper end. Figure 10 is a curve from JOMINY's article in METAL PROGRESS for November 1940 on "Commercial Applications of Hardenability Tests", and shows the cooling rate of various points along the surface of the test piece, in °F. per sec. when passing through 1300° F. (a temperature between the critical transformation temperature and the "gate" of the "S" curve).

In this manner it is possible to determine from the JOMINY test the *time* required for any given part of any ordinary sized round to pass through this "gate", the rate of cooling at any location of any part made from the same steel, as quenched either in oil or water. We have also a means of determining the time which a given piece must be held in water to insure full quenching and the maximum time it can be left in the water quench to prevent severe quenching stresses (see Fig. 11). We are also able to determine from the hardness curve of end-quenched specimens the speed of quenching a given section which will be necessary to insure a homogeneous martensitic structure free from boundary ferrite.

It is believed that hardenability tests, and especially the JOMINY type of test, will find widespread use as a means for selecting steel as soon as the metallurgist and engineer become more familiar with its use. Certainly it makes it easier to obtain a proper relationship between hardness (tensile strength) and stress than any means now available. It gives probably more information as to the structural properties of a given heat or bar of steel than any other simple test. It brings out clearly that steels of substantially uniform analysis, annealed in the same way, may have considerably different hardenability (Fig. 12) unless the heating before quenching is properly adjusted as to time and temperature to homogenize the austenite (Fig. 13, on page 470).

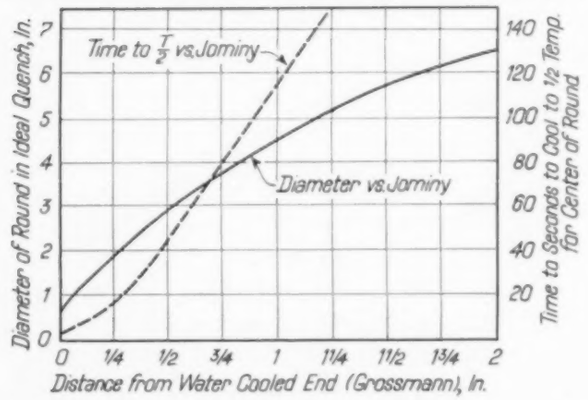

Diameter of Round in Ideal Quench, In.
Time to Seconds to Cool to ½ Temp. for Center of Round
Time to ½ vs. Jominy
Diameter vs. Jominy
Distance from Water Cooled End (Grossmann), In.

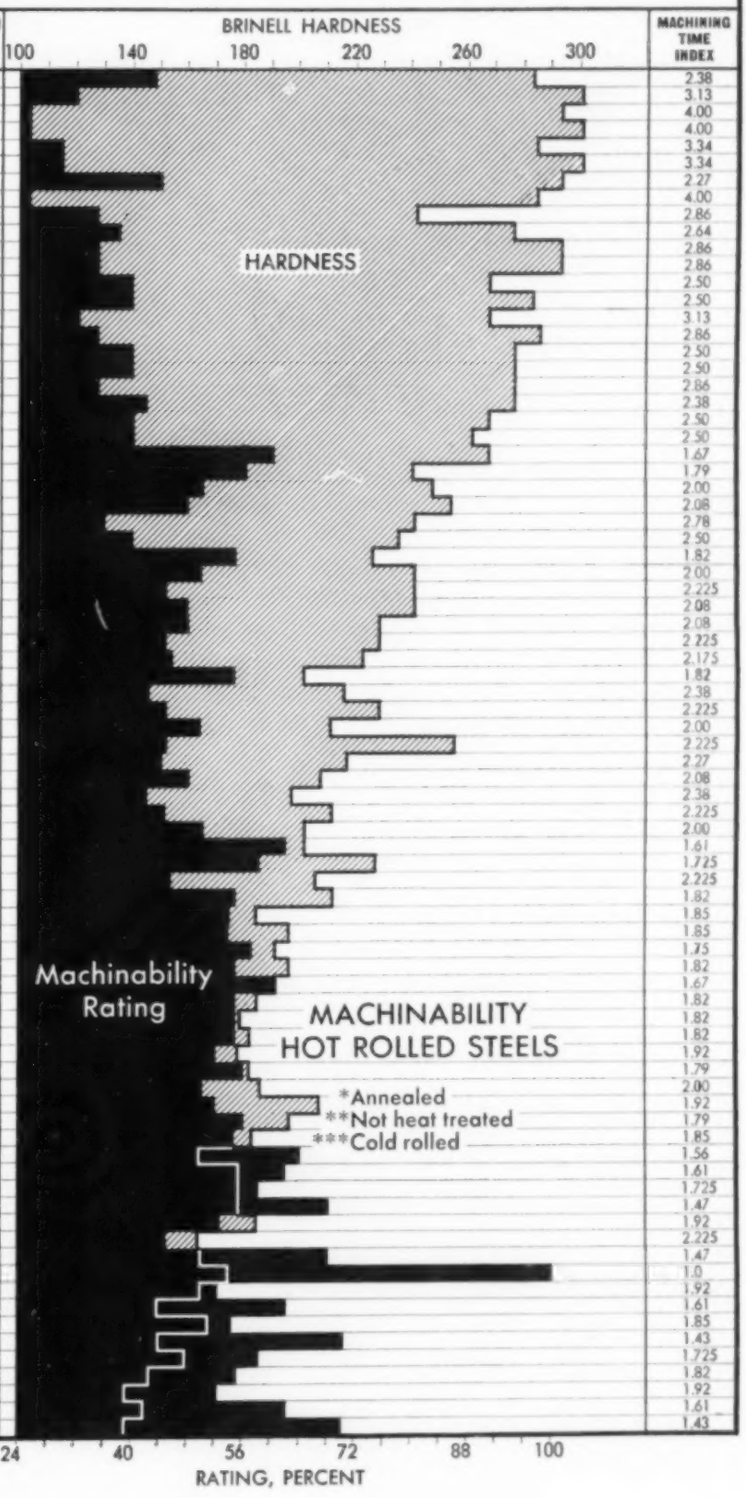
Fig. 11 — Curves Showing the Relation Between the Distance From the Quenched End of Sample in Jominy Hardenability Test, and the Time Required to Cool the Sample to Half Quenching Temperature (Dotted Line), as Well as the Relation to the Speed of Cooling at the Center of Round Specimens Quenched in Water Under Ideal Conditions (Grossmann)

Machinability of Hot-Rolled Steels

By James Sorenson and *Wallace Gates*
Chief Metallurgist — Head, Standards Dept.
The Four Wheel Drive Auto Co., Clintonville, Wis.

Relative time for removing unit volume of the S.A.E. steels in a well-equipped machine shop, averaging such variations as tools, operators, types of machines, speeds and feeds. The tools or the material generally determine the depth of cut. Courtesy Four Wheel Drive Auto Co. and *Product Engineering*

S.A.E. NO.	ULTIMATE STRENGTH LB. PER SQ. IN.	ELASTIC LIMIT LB. PER SQ. IN.	ELONGATION IN 2 IN. PER CENT	REDUCTION OF AREA PER CENT	MACHINING TIME INDEX
4340	150,000	125,000	22	56	2.38
4150	150,000	125,000	18	45	3.13
3340	150,000	125,000	20	54	4.00
2350	150,000	125,000	16	42	4.00
3250	145,000	120,000	16	48	3.34
2340	145,000	120,000	18	50	3.34
4640	142,000	125,000	21	60	2.27
6150**	140,000	105,000	16	42	4.00
3340**	140,000	100,000	20	50	2.86
3140	140,000	115,000	18	48	2.64
2330	140,000	110,000	18	50	2.86
6135	138,000	120,000	20	52	2.86
5140	135,000	115,000	20	50	2.50
4140	135,000	122,000	18	55	2.50
3240	135,000	115,000	18	50	3.13
6130	130,000	115,000	20	55	2.86
4130	130,000	115,000	20	55	2.50
3312	130,000	110,000	22	58	2.50
3230	130,000	105,000	18	50	2.86
6140**	125,000	110,000	15	40	2.38
3220	125,000	95,000	18	45	2.50
3130	125,000	105,000	20	50	2.50
X1335	125,000	100,000	18	45	1.67
4640**	120,000	90,000	12	40	1.79
4620	120,000	90,000	20	58	2.00
3312**	120,000	90,000	22	55	2.08
3250**	120,000	95,000	18	45	2.78
9260*	115,000	82,000	18	42	2.50
4820	115,000	75,000	20	50	1.82
4615	115,000	88,000	20	60	2.00
3120	115,000	90,000	19	60	2.225
2320	115,000	88,000	20	55	2.08
2315	110,000	84,000	22	60	2.08
9255*	110,000	80,000	20	44	2.225
5140**	110,000	85,000	20	50	2.175
4815	110,000	80,000	20	50	1.82
3340*	110,000	90,000	22	58	2.38
2515	110,000	68,000	30	65	2.225
2350*	110,000	80,000	22	45	2.00
1040	110,000	90,000	18	45	2.225
3250*	108,000	80,000	22	50	2.27
6150*	105,000	75,000	24	50	2.08
3450	105,000	75,000	22	52	2.38
3240*	105,000	75,000	24	50	2.225
6140*	100,000	70,000	25	55	2.00
4640*	100,000	85,000	18	45	1.61
4340*	100,000	80,000	25	60	1.725
1095*	100,000	60,000	22	45	2.225
1035	100,000	70,000	24	55	1.82
6135*	95,000	65,000	18	50	1.85
4150*	95,000	70,000	25	56	1.85
3140*	95,000	65,000	22	55	1.75
2340*	95,000	66,000	25	58	1.82
1030	95,000	65,000	24	55	1.67
4820*	92,000	65,000	25	60	1.82
6130*	90,000	60,000	25	60	1.82
5140*	90,000	55,000	25	55	1.82
4815*	90,000	70,000	28	65	1.92
4140*	90,000	65,000	28	58	1.79
3312*	90,000	75,000	28	62	2.00
3230*	90,000	65,000	25	54	1.92
3130*	90,000	60,000	30	55	1.79
6120	85,000	65,000	30	60	1.85
4620*	85,000	56,000	30	60	1.56
4130*	85,000	60,000	30	65	1.61
2330*	85,000	62,000	26	58	1.725
1040*	85,000	50,000	22	54	1.47
3220*	80,000	68,000	28	60	1.92
2515*	80,000	65,000	32	70	2.225
1035*	80,000	48,000	28	58	1.47
1112***	80,000	60,000	15	40	1.0
6120*	78,000	60,000	35	70	1.92
4615*	78,000	48,000	33	65	1.61
2320*	76,000	58,000	30	60	1.85
1030*	75,000	45,000	28	60	1.43
2315*	74,000	55,000	32	62	1.725
3120*	70,000	60,000	32	65	1.82
1070	65,000	40,000	32	60	1.92
X1020	62,000	48,000	30	58	1.61
1120	55,000	41,000	32	60	1.43



Carburizing Steels

While the preceding discussion has been confined primarily to the so-called heat treating types, much of it is applicable to the carburized case of lower carbon steels.

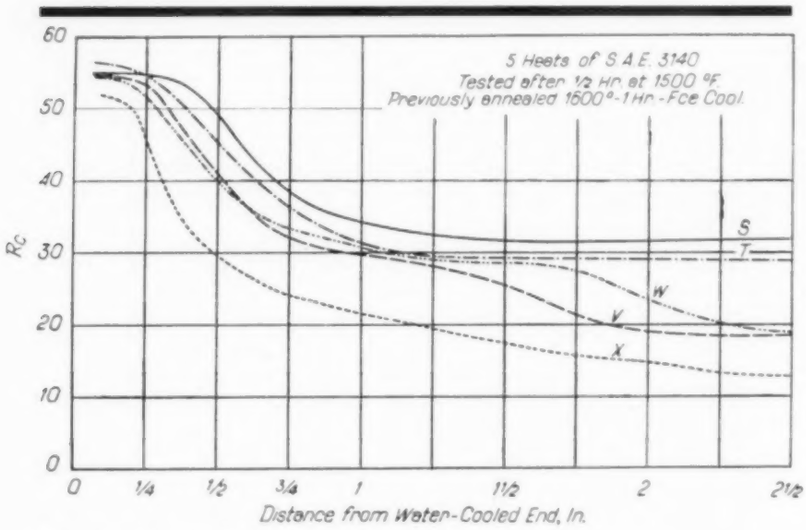


Fig. 12 (above) — End-Quench Test on Five Heats of S.A.E. 3140 Which Vary Considerably in Hardenability After Annealing 60 Min. at 1600° F. (Williams)

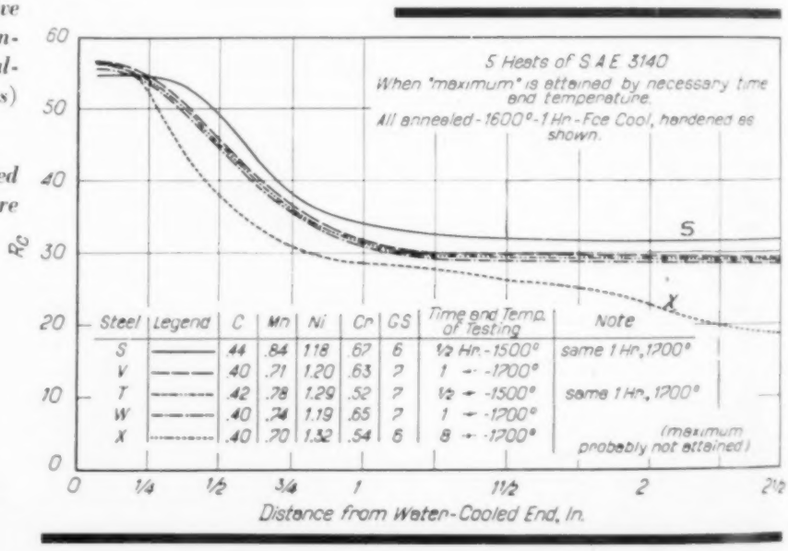

5 Heats of S.A.E. 3140
When "maximum" is attained by necessary time and temperature.
All annealed - 1600°-1 Hr.-Fce Cool, hardened as shown.
S
X
Rc
60
50
40
30
20
10
0
0
¼
½
¾
1
1½
2
2½
Distance from Water-Cooled End, In.
Steel | Legend | C | Mn | Ni | Cr | GS | Time and Temp. of Testing | Note
S | 44 | .84 | 1.18 | .67 | 6 | ½ Hr.-1500° | same 1 Hr., 1700°
V | .40 | .71 | 1.20 | .63 | 7 | 1 → -1700° |
T | .42 | .78 | 1.29 | .52 | 7 | ½ → -1500° | same 1 Hr., 1700°
W | .40 | .74 | 1.19 | .65 | 7 | 1 → -1700° |
X | .40 | .70 | 1.32 | .54 | 6 | 8 → -1700° | (maximum probably not attained)

Fig. 13 (at right) — Same Steels as Tested in Fig. 12 After Time and Temperature Prior to Quenching Has Been Adjusted for Maximum Hardenability

Maximum properties are desired in carburizing steels because of the fact that whereas steel is casehardened primarily to produce a wear resistant surface, for many applications this surface must also have sufficient ductility and compressive strength to take care of very suddenly applied tension or compression loads which might be of a highly concentrated nature. We are primarily interested in the hardness and tensile strength of the core and in the hardness and ductility of the case.

Now, the low carbon steels usually employed for casehardening have much greater ductility in the quenched condition than the high carbon case, so it is difficult to stress them dangerously in the usual application without complete failure of the case. For this reason it is a simple matter to improve core properties but a difficult matter in many instances to build up a satisfactory combination of properties in the case. Where resistance to abrasion is of primary importance it may be necessary to have a definitely hyper-eutectoid case, for the direct advantage due to the presence of excess carbides. If some degree of ductility is required it is necessary that the structure be fine grained and of the "abnormal" type to avoid a continuous brittle carbide network.

There is no doubt that higher carbon steels can be used for carburizing, providing they are fine grained. Where ductility of the case is of considerable importance the carburizing procedure, if possible, should be such that a eutectoid composition is obtained in the case. This, of course, has been recognized for many years in the bearing and other industries where a great deal of money has been spent to obtain such structures after carburizing.

If a steel has a case of approximately eutectoid composition the principal advantage of alloy additions lies in their ability to obtain full hardening with oil quenching so that change in shape after heat treatment is a minimum. These steels are ordinarily used for parts such as gears and bearings where warpage prevents water quenching. However, due to the high car-

bon content in the relatively small section of the usual carburized piece, the amount of alloy required to obtain full surface hardening is small. Thus, in the ordinary automotive part the combination of approximately 0.80 to 1.00% manganese with a very small percentage of other elements such as molybdenum, chromium, vanadium or nickel will provide a case which will harden fully when quenched in oil. In work which is quenched directly from the carburizing box most of these low alloys will also harden fully in the core, providing the carbon content is properly adjusted, so that very satisfactory work can be obtained from carburized steels containing approximately 1.00% manganese and less than 0.5% of any one of several other alloys.

Some of the alloy steels, such as the chromium group, when carburized and quenched will be soft to the file. This has been the basis of some criticism. The soft skin is apparently caused by the excess precipitation of carbide when cooling through the A_{cm} range, so that a combination of carbide and ferrite is formed which will be soft to the file. This skin is superficial, and on any work which is ground or lapped prior to service it will prove no detriment. The chromium steels require a higher heat treating range and faster handling from the carburizing boxes when quenched directly, but do have a surface which, when properly treated, is somewhat more resistant to abrasion than the straight carbon or nickel steels.

Elements such as nickel, manganese and molybdenum have the advantage that they lower the transformation temperature and simplify the problem of quenching from the box. They also tend to increase the hardness of the ferrite and thereby improve the machinability of these low carbon steels — especially for such operations as broaching. The nickel-molybdenum and manganese-molybdenum low alloy steels have proven to be two of the most satisfactory for all-purpose applications, and will increase in use as their advantages are realized.

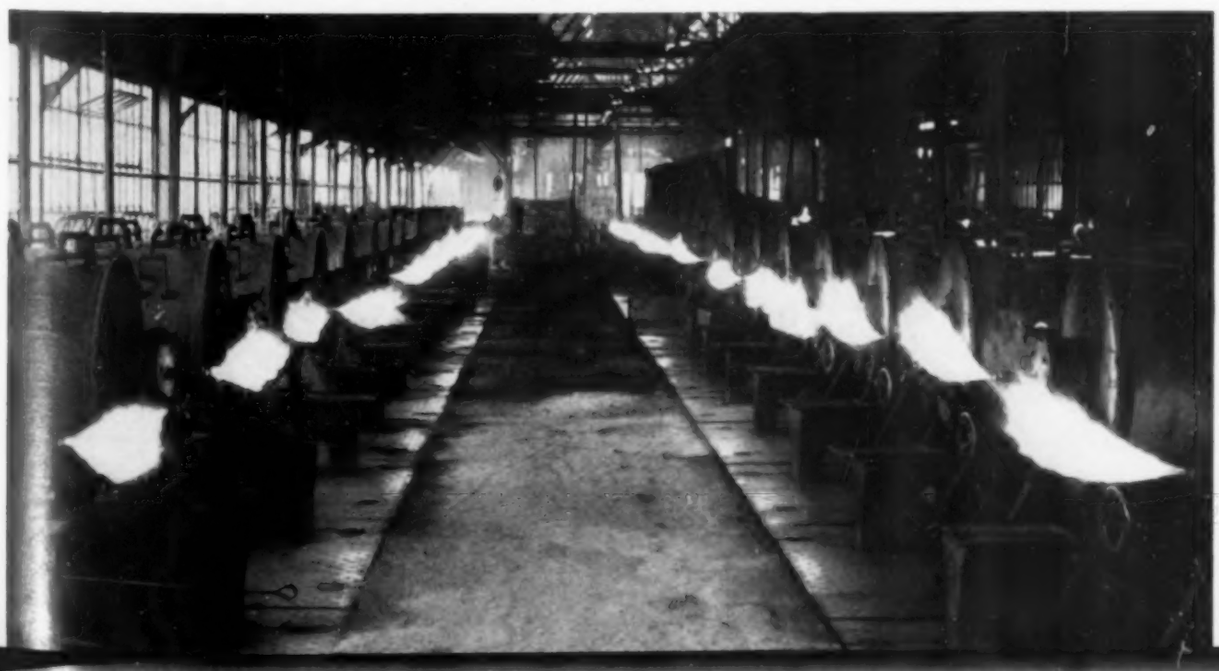
Best Carburizing Practice

To develop the best properties in carburizing steels, therefore, it is necessary that the carbon content be such that when oil quenched the core strength will be satisfactory. Since the *ductility* of the core is usually of minor importance, the strength of core to suit a given case depth can be obtained most easily by increasing the carbon content.

The maximum properties *in the case* are developed by having a steel of the fine-grained type, carburized to a carbon content as close as possible to eutectoid composition, and quenched to obtain a minimum of retained austenite. One advantage of the low alloy combinations is that the amount of retained austenite is a minimum, so they lend themselves primarily to direct quenching. With the heavier cases and direct quenching the case strength of some of the higher alloy steels is less than that of the lower alloy steel, due to the presence of much austenite after hardening.

It is, therefore, advisable to make certain that steels are used for carburizing which do not have too much alloy, whose case analyzes as close to eutectoid carbon as possible, and the carbon content of the core is sufficient to provide ample strength to support whatever case depth is decided upon.

Fig. 14 — Battery of Gas Carburizing Furnaces at Timken Roller Bearing Co., Canton, Ohio, a Pioneer in the Development of Direct Quenched, Carburized, Low Alloy Steels



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Decarburizing Iron Shot*

By Bo Kalling and Ivar Rennerfelt

THE POSSIBILITY of decarburizing pig iron without melting has been known and utilized for a long time. Current methods, however, are unsatisfactory because the iron ore used as an oxidizing agent tends to sinter at temperatures near 1800° F.; furthermore, the reactions are endothermic. The "R.K." process offers a new method of converting pig iron into a low carbon substitute for steel scrap, and differs from previous methods chiefly by the fact that carbon is oxidized by the gaseous carbon oxides instead of solid iron oxides, and that the process is carried on continuously by feeding the material through a rotary furnace.

In the experimental work at Avesta, Sweden, the granules were fed continuously into a rotary furnace, 30 in. diameter inside the refractory lining and 11 ft. long. Along the inclined axis of this kiln was a pipe with many side nozzles carrying appropriate gas-air mixtures.

Decarburization is generally favored by an increase in temperature. The Fe-C-O equilibrium diagram shows that at 1800° F. it should be possible to lower the carbon to about 0.04% without oxidation of iron, and at 2000° F. to about 0.02% carbon.

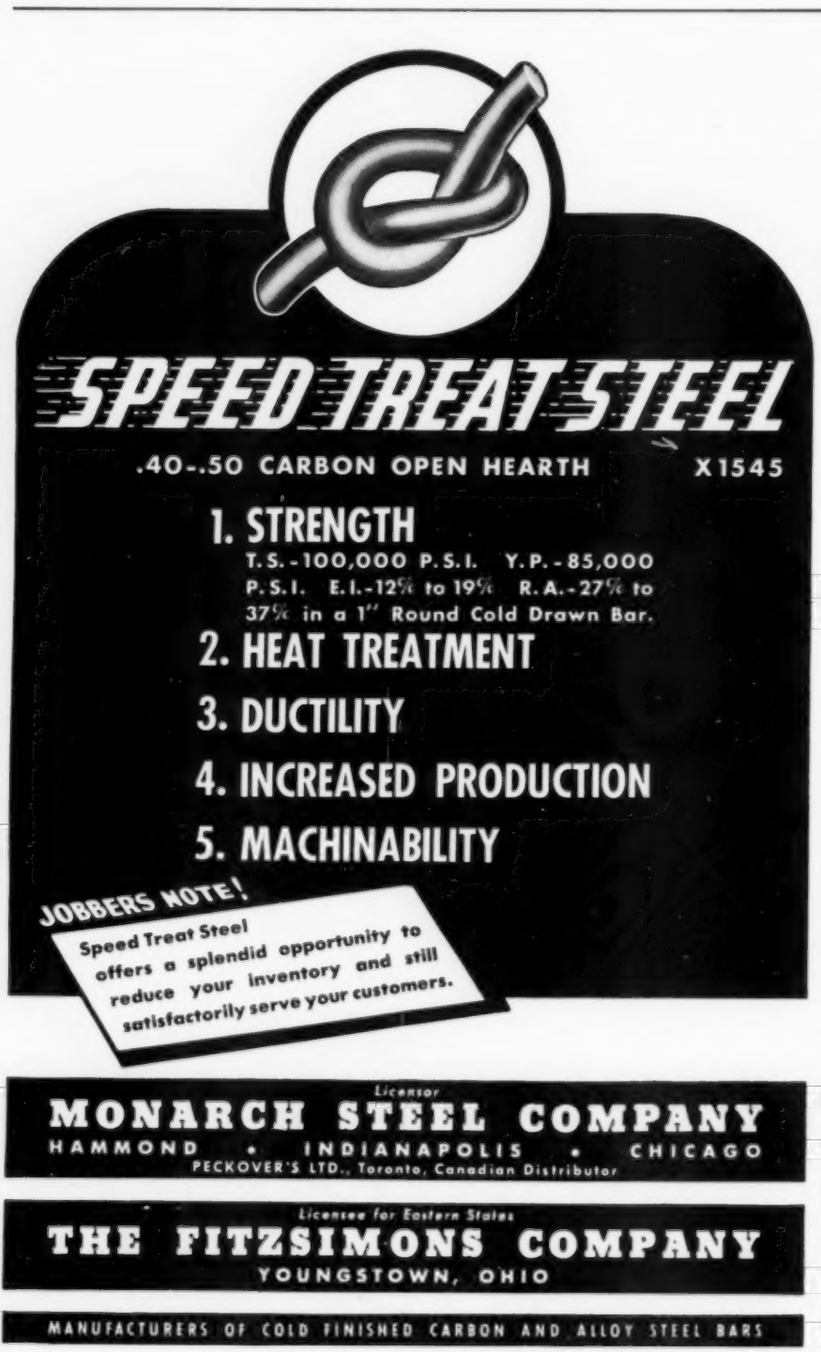
However, in order that a process may be utilized technically a sufficiently high rate of reaction is also necessary. Since diffusion of the oxygen into the iron must always occur very slowly, there is no need to take into account anything but the diffusion of carbon to the surface of the granules.

This diffusion rate should be proportional to the decrease of concentration per unit length in the austenite phase. It is thus of great importance that the carbon content at the surface be kept as low as possible. Calculations also indicate that the time of decarburization should be proportional to the square of the radius of the granules.

An increase in temperature causes more rapid diffusion of the carbon as well as increasing its solubility in austenite (without which it cannot diffuse). Silicon contents of less than 1%

(Continued on page 482)

*Abstract of "Decarburization of Granulated Pig Iron: The 'R.K.' Process", *Journal*, Iron and Steel Institute, Vol. 140, No. II (1939), p. 137.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J&L STEEL

TO AMERICAN INDUSTRY

Iron Shot

(Continued from page 474)

have little effect upon the rate of decarburization; with increased silicon the rate successively decreases, possibly owing to formation of a passivating oxide film. Manganese, up to 2.5%, has no effect.

The first plant for industrial production by the "R.K." process was put in operation in 1938 at the Fagersta Steelworks. Its chief purpose was to produce a decarburized iron with the lowest possible carbon content. A granulation plant was built to produce grains of pig iron as round as possible and of a smaller diameter than the maximum desired for decarburization.

A 24-hr. trial was made with a crushed granulated iron. This product did not prove as suitable for the process as the granules in their original state. The sharp-edged grains hooked into one another, and the charge did not flow so evenly in the furnace. The angle of slip of the charge increased and at the highest temperature, about 1925° F., it was nearly vertical.

In the granulation plant the pig iron is poured from a ladle into an open tun dish, from which it flows through a hole in the bottom in a thin jet toward a rotating drum. This has a surface made of parallel slats of wood, which shatter the jet and throw the iron drops down into the water sump just below. In order to keep the wood slats moist and to prevent their destruction, an ample quantity of water is flushed on the wheel immediately before the iron strikes it. The total quantity of water required for the granulation depends on the temperature of the overflow; it was generally so regulated that the water in the tank rose to about 160° F. About 5 tons of pig iron is granulated at a time, at a rate of about 450 lb. per min. The analysis has a great influence on the behavior of the pig iron during granulation. A high silicon content, for instance, tends to produce hollow grains, especially the coarser ones.

When the output of the furnace described below was 6 to 7 tons per 24 hr. the carbon content was easily kept below 0.10%, sometimes even below 0.05%. However, when the feeding rate was increased to 13 tons, the final carbon analysis became irregular and rose considerably above 0.10%.

A decarburization furnace intended to produce 6 to 10 tons per 24 hr. was erected. It had an inner diameter of 3½ ft. and an inside length of 13 ft. The brick lining is 9 in. thick and consists of an outer layer of

(Continued on page 486)

The Question of the hour:

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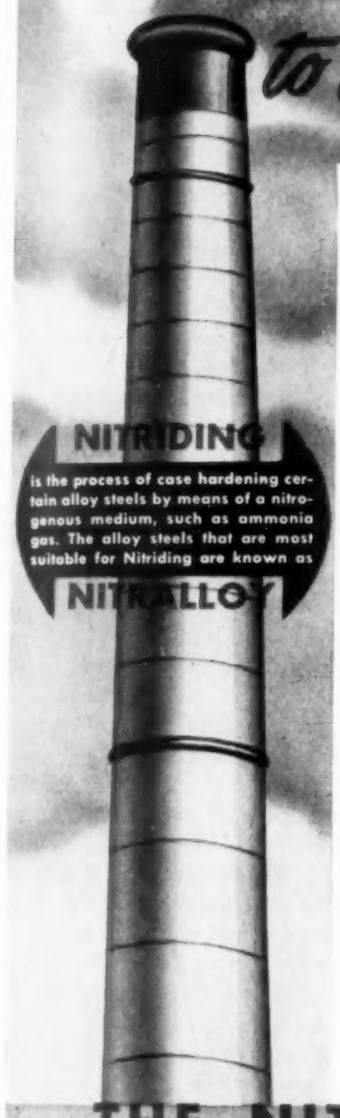
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CHROMIUM	0.9 TO 1.80
ALUMINUM	0.75 TO 1.50
MOLYBDENUM	0.15 TO 0.60

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WARMAN STEEL CASTING CO.....LOS ANGELES, CAL.

720

Iron Shot

(Starts on page 474)

insulating bricks 4½ in. thick and inside of this a 4½-in. layer of firebrick. The diameter of the inlet opening is 14 in. and of the outlet opening 10 in.

After leaving the furnace, the granulated iron is cooled in a short drum divided in sections by a number of transverse steel plates, each with a semicircular opening at the periphery. The openings are staggered, plate to plate, so that one of them is always completely covered by the material. This arrangement makes it possible to discharge material during the rotation of the drum, and at the same time to prevent the gas from escaping through the same opening. The longitudinal inclination of the furnace, which is adjustable, has hitherto been about 3%.

Tests proved that the heat required could be supplied by the combustion of the reaction gas with the addition of blast furnace gas. A special burner was designed consisting of three concentric pipes whose exposed parts are made of heat resisting iron-chromium-nickel alloy. It is placed along the axis of the furnace. The outermost pipe is closed at the end but it has a number of openings along its length. Through the innermost pipe is introduced the blast furnace gas which enters the furnace about two-thirds the way from charge opening to discharge. It is burned by a regulated amount of "primary air" which is introduced between the walls of the inner pipe and its surrounding jacket. The "secondary air", supplied through the nozzles of the outermost pipe at right angles to the charge, brings about the main decarburization. The burner and the blower, which is common to the primary and the secondary air, are suspended from a trolley so the burner can be adjusted or even removed entirely.

According to the experience at Fagersta, it will be possible to keep the average carbon content constantly below 0.05%, provided the production rate is properly adapted to the dimensions of the furnace and to the grain size of the granulated iron. The average carbon content of grains under 2 mm. is not more than 0.03%. Grains over 2 mm. average 0.09% carbon. The Fagersta furnace is now used in continuous operation.

A furnace of this type installed at the Uddeholms Aktiebolag Hagfors Steelworks is designed to produce 12 to 20 tons per 24 hr. of metal containing 0.05 to 0.50% carbon. Another at the Vuoksenniska Steelworks can produce 20 tons per 24 hr. with 0.40% carbon.

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Company.....
Address.....

Along with notable changes in the forging equipment (described in detail on page 543) have been even more striking improvements in the automatic hardening furnaces for high explosive shell. A five-fold increase in capacity, and incomparable uniformity is now achieved in this new equipment at Frankford Arsenal

Advances in High Explosive Shell Manufacture

PREPAREDNESS has always, and naturally enough, been the slogan as well as the function of the Ordnance Department of the U. S. Army. One phase of its work in keeping America prepared to "repel boarders" (to borrow a naval term) has been to improve the technique of forging, machining and heat treating high explosive shells. Through extensive research great advances have been made in the manufacturing methods for the production of shells today as compared with those produced during the World War. Most of this research has been carried on and the necessary shop practices developed at the Frankford Arsenal in Philadelphia.

Prior to the World War (1914) only six ordnance arsenals and two civilian factories in this country were equipped for the production of artillery ammunition, yet by the time the Armistice was signed in 1918 nearly 8000 plants were working on ordnance contracts! Startling as this increase seems, it is dwarfed to insignificance by present expansion. For example, contrast the output of one arsenal in 1918, which was less than 600,000 shells, with the fact that in one 45-day period recently the Army and Navy contracted for 123,000,000 of 20-mm., 37-mm., and 40-mm. shells alone.

Today, millions of shells of various calibers (some entirely new) are being turned out by mass production methods at U. S. Ordnance Arsenals, huge steel mills and forging plants, and also by a myriad of small forge and machine shops. The change-over from civilian to shell production, under the guidance and leadership of the Ordnance Department, has been nothing short of amazing. Manufacturing, training and educational orders by the Ordnance Department, throughout the "disarmament season", have been a most vital factor in eliminating costly mistakes that would otherwise have occurred during this transition period.

Improved forging technique is one big factor in the development of this industry. In the days of the World War No. 1 forging was limited to the pierce-and-draw method. With the standards of shop practice then in vogue for this method, it was impossible to forge the cavity of high explosive shell to the close tolerances required. This made it necessary to bore or finish machine the inside.

Today, because of improved shop practice, the development of the Witter shell forging process, the Assel cross roll mill, the forging upsetter, and other devices, it is possible to hold the shell cavity, in the as-forged condition, to the dimensional tolerances required in the finished shell. This advance alone means a great increase in the quantity of shells produced per man per day.

These close forging tolerances also allow the use of smaller billets for the same size shell. In some types the saving in the weight of raw steel amounts almost to one third. This directly

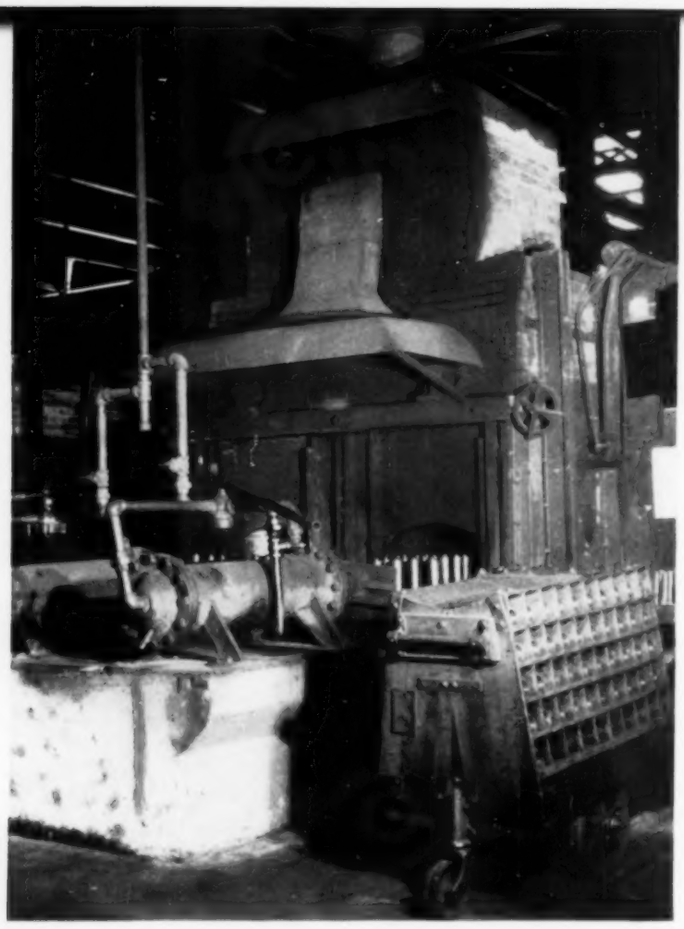


Fig. 1 — Obsolete Shell Hardening Furnace, Fuel Fired for Smoky Flame. The designer certainly put a substantial foundation under the pusher!

affects machining in that there is less metal to take off, tool (and die) life is increased, and output rates are stepped up materially. The practical application of multi-spindle automatic machines equipped with carbide tools are also great achievements in the machine tool industry and add another rung to the ladder of greater production — but these have been exhaustively treated elsewhere in a number of recent articles, and will not be discussed in this article dealing primarily with heat treatment and furnaces therefor.

Shell Steel

Towards the close of the World War the chemical requirements for shell steel had pretty well crystallized into the following analyses:

Carbon	0.45 to 0.65%
Manganese	0.50 to 0.90
Phosphorus	0.055 max.
Sulphur	0.06 max.
Silicon	0.35

Steels purchased according to these specifications could be rejected upon analysis if other elements were found to be present. However, if nickel, copper or chromium were present, the steel could be accepted, at the discretion of the inspector, provided the quantities did not exceed 0.50, 0.25 and 0.30% respectively, but the sum of the quantity of the three (if all three were present) could not exceed 0.50%.

In order to preserve machinability and uniformity of heat treatment in steel for shell, and shrapnel of less than 8-in. caliber, it was necessary to guard against a possible combination of high carbon and high manganese in the same heat. Therefore it was specified that the "carbon content times 3, plus manganese content" should not be greater than the index number 255.

In addition to the chemical analysis certain physical requirements were also mandatory. Test bars (2 sq.in. cross section) were heated to 1600° F. for 30 min. and quenched in oil. Drawing details were left to the steel mill but the following minimum physical spec-

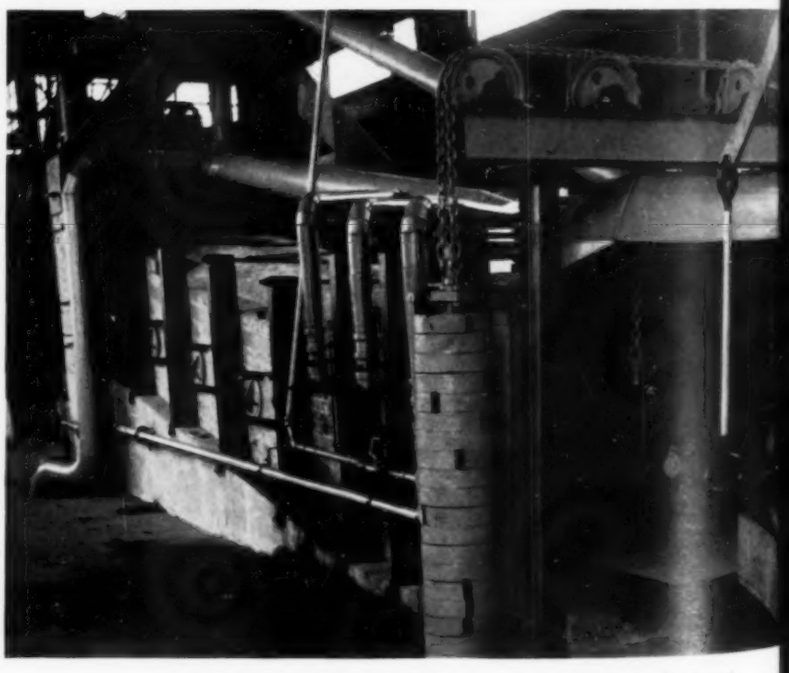
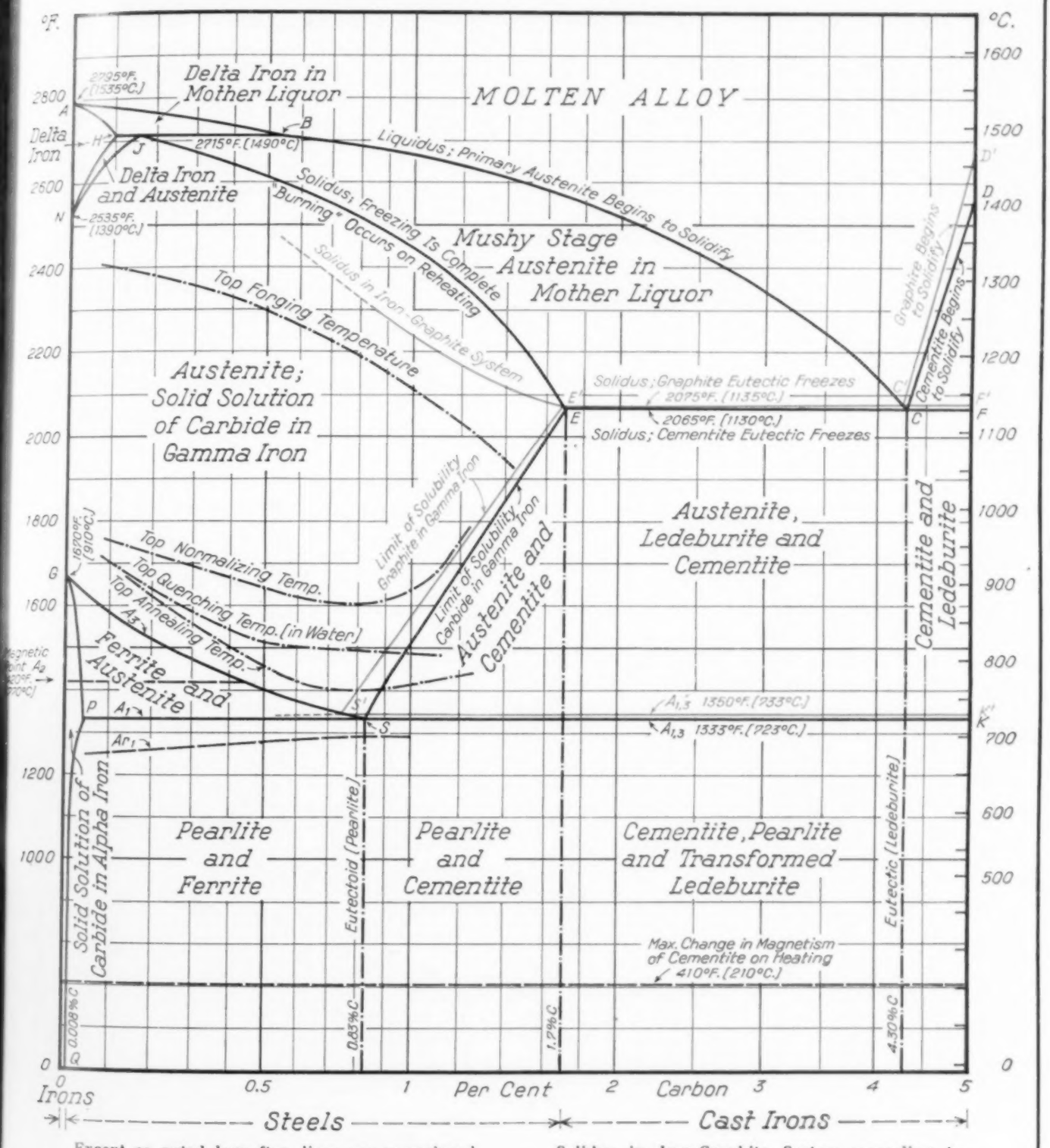


Fig. 2 — Older Type of Furnace With Inclined Hearth Used for Both Hardening and Drawing Shells

Iron, Iron Carbide Equilibrium Diagram

Approximate Iron-Graphite Diagram in Red



Except as noted hereafter, lines are reproduced by courtesy of The Engineering Foundation from diagrams published in one of the Alloys of Iron Monographs: "Alloys of Iron and Carbon," Vol. I on Constitution, by Samuel Epstein.

Delta iron region and solidus by Frank Adcock, *Journal* of the Iron and Steel Institute, 1937-I.

Forging and heat treating temperatures from Recommended Practices, 1939 ⊕ Metals Handbook.

Solidus in Iron-Graphite System according to Kaya, Honda and Endo, *Science Reports*, Tohoku Imperial University, 1925 and 1927.

Ar_1 according to Hoyt and Dowdell, "Metals and Common Alloys," for cooling rates of 1° C. in 3 sec.

Line GPQ according to J. H. Whiteley, *Journal*, Iron and Steel Institute, 1936.

Solidus in graphite system left of E' as suggested by Harry A. Schwartz.

ifications (or their equivalent) were required to be met:

	Combination 1	2	3
Tensile strength, psi.	90,000	95,000	100,000
Elastic limit, psi.	50,000	55,000	60,000
Elongation in 2 in.	17%	16%	15%

The greatest advance today over these steels, from the production standpoint, has been the adoption of high sulphur, free machining, air hardening steels that do not require complicated heat treatment. These steels were used for the smaller sizes only. A typical analysis follows:

Carbon	0.35 to 0.45%
Manganese	1.35 to 1.65
Sulphur	0.075 to 0.15
Phosphorus	0.045% max.

This corresponds to the analysis of the free cutting steels S.A.E. X-1340.

However, shell steel research is being prosecuted at an accelerating pace and what is practice today may be obsolete tomorrow. While plain carbon steels are generally still in use for the larger size shells, which are heat treated, modifications of chemical requirements are being made right along, in order to take advantage of the findings of this research. While these modifications are more or less military secrets it can be disclosed that at least one shell is being made of steel of the following analysis, nearly corresponding to S.A.E. 1340:

Carbon	0.35 to 0.45%
Manganese	1.60 to 1.90
Sulphur	0.050% max.
Phosphorus	0.045% max.

We are a long way from the ultimate yet and can look forward to better steels in the not distant future.

In this respect we might take a quick glance at what others started with.

German steels used for high explosives dur-

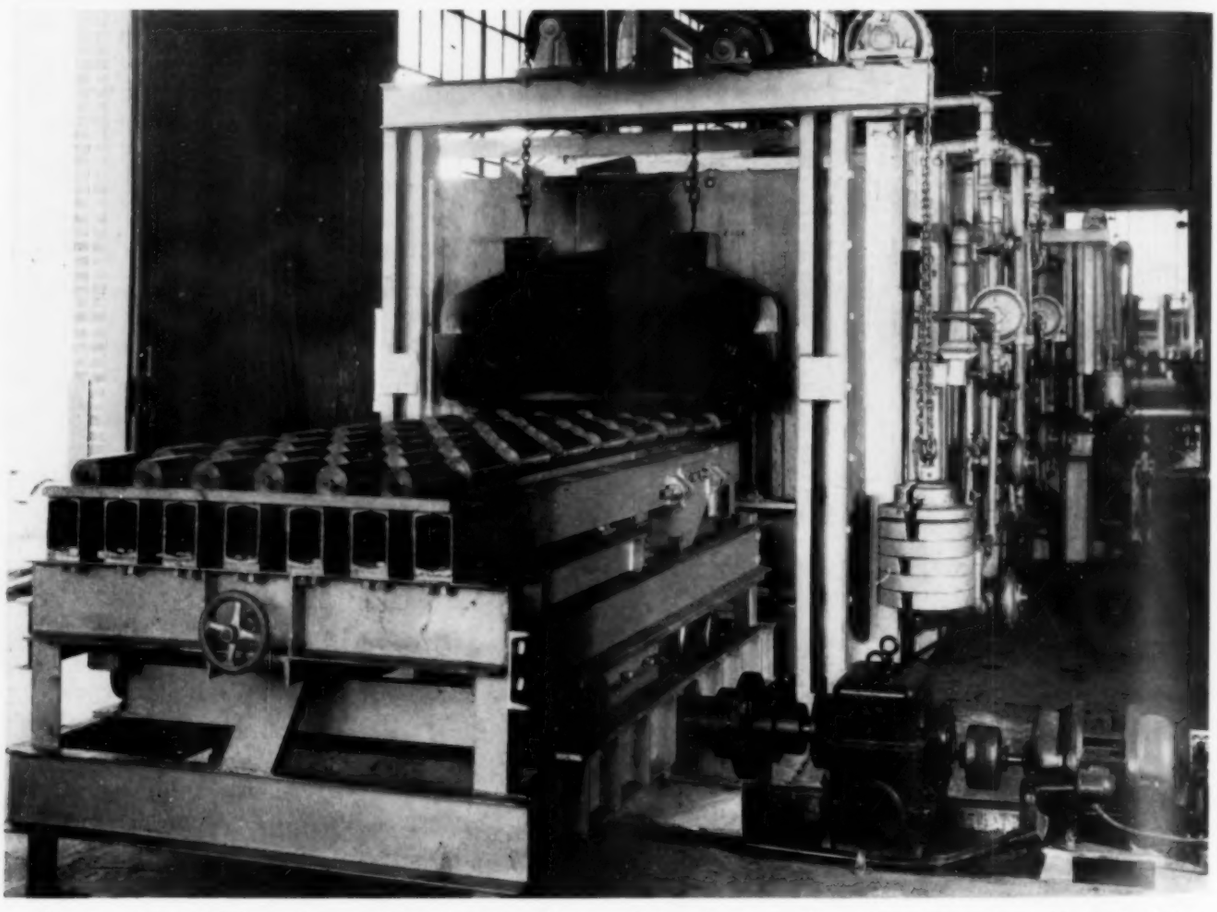


Fig. 3 — Most Modern Furnace Line for Quenching and Drawing High Explosive Shell, 5 In. and Thereabouts. View shows charging table and drive mechanism for walking beam type of conveyor

ing the World War were on the order of the following analyses:

	Minimum	Average	Maximum
Carbon	0.40%	0.75%	1.12%
Manganese	0.40	0.93	1.40
Silicon	0.01	0.28	0.80
Sulphur	0.01	0.05	0.085
Phosphorus	0.01	0.06	0.105
Copper	0.0	....	1.00

These analyses were obtained from shell fragments picked up in the battle zone, and show that the shell steel used by the enemy at that time would never have passed American, French, or even Russian inspection.

Heat Treating Equipment

Development in heat treating equipment for use with the plain carbon steels has been rapid and radical. A typical heat treating program of one company, making shells back in the World War days, employed batch type, kerosene-fired furnaces holding from 60 to 70 shells at a time. Heating-up periods ranged from 50 to 70 min. plus 10 more for soaking at what was hoped to be 1550° F. At first oil and then water was used for quenching and it varied all the way from 80 to 180° F. in temperature. Shells were immersed, base down, so as not to allow water to get inside through the nose. Drawing included a preheat to 800° F. (in waste gases from the lead pot) for 8 min. and a 5-min. soak in lead at 1100° F. (eight shells to each lead bath).

Such variations in quenching naturally caused variations in the hardness of the product. A tendency toward a soft nose was partially overcome by drawing the shell-base down in the lead bath. This left the nose somewhat exposed to be drawn at a lower temperature. Hardness desired was 32 to 42 scleroscope.

Later on, continuous type furnaces came into vogue, and each served the dual purpose

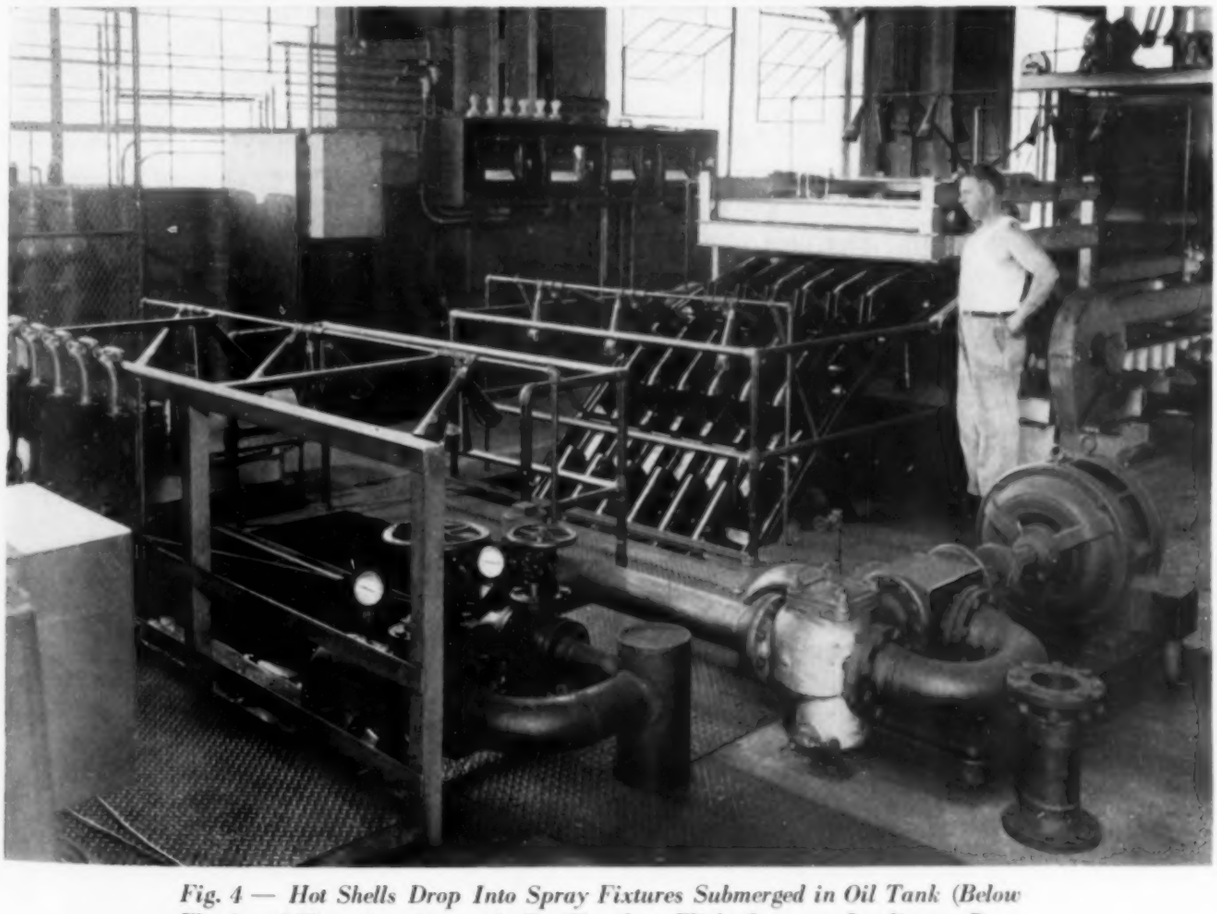


Fig. 4 — Hot Shells Drop Into Spray Fixtures Submerged in Oil Tank (Below Floor) and Then Are Automatically Placed on Flight Conveyor Leading to Draw Furnace. (Horn shaped devices over tank are part of the fire protection system.)

of hardening and drawing. Of the inclined hearth type (Fig. 2), a production of 88 shells (96 lb. each) per 8-hr. shift was obtained on a heating schedule of 2 hr. 20 min. Burners were manually controlled and, in spite of recording pyrometers, physical characteristics varied greatly. Hot shells were removed by hand for quenching. After hardening a pile of work at 1550° F., the temperature of this furnace was dropped to 1100° F. and the same shells were drawn. With this operation a rate of 124 per shift was attained with a heat cycle of 1 hr. 38 min.

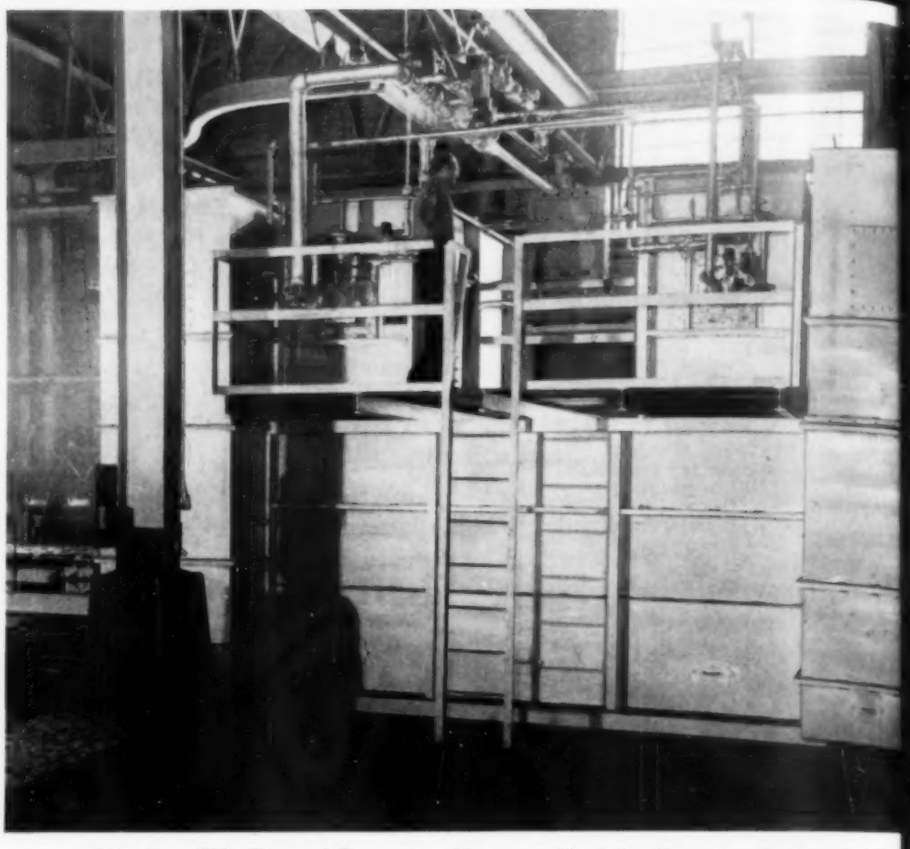


Fig. 5 — Side View of Convection Furnace Used for Drawing the Quenched Shell. Two air heaters, each with fan housing alongside, are mounted on the ro

A few years ago the Frankford Arsenal procured an automatic quench and draw set, both hardening and drawing furnaces being of the open-fired, walking beam type. This set accommodated only one size of shell and operated on a 4-min. cycle. Oil in the quench was maintained automatically at temperature and fairly uniform results were obtained.

Automatic Furnaces

Recently there has been put in operation at the same arsenal a unit which is the last word in automatic heat treating, including hardening, quenching and drawing. Control is so close that variations in the physicals of the shells are held within three points Rockwell. While the hardening furnace is quite similar to the old one, the draw furnace is of the convection type. The unit accommodates three different sizes of shells and has a production rate of 1368 shells in 24 hr. Shell sizes are 4.7 in., 5 in., 155-mm., and other comparable sizes. This unit was developed and built by the Surface Combustion Corp. of Toledo, Ohio.

The conveying mechanism of both furnaces consists of six conveyors. Each conveyor has two sets of parallel rails, a fixed set and a set of walking beams, both of high chromium-nickel alloy. The fixed rails extend beyond the furnaces at the front ends, forming the charging table onto which the shells are loaded (Fig. 3). From there the shells are picked up and moved through the furnaces by the walking beams, six rows at a time. The walking beam rails are carried by alloy cross beams, on the bottom of which are wedge shaped surfaces which engage corresponding surfaces on two longitudinal drive-rails to lift and carry the load. Shells rest on projecting fingers on both fixed and moving rails to allow free circulation of heat. The fixed rails rest on top of piers; thus space is provided for the walking beams as well as for free circulation of hot atmosphere.

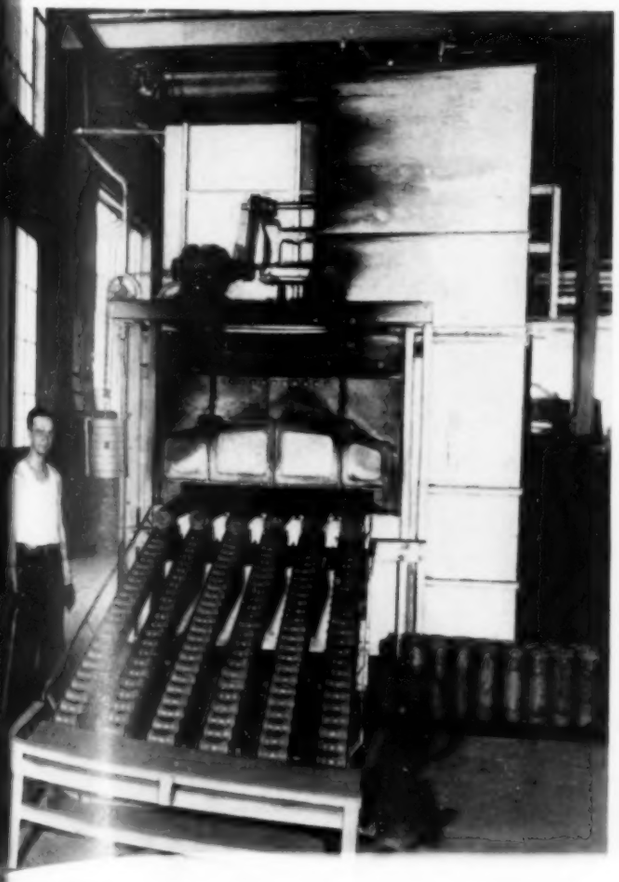
Shells, after attaining the necessary temperature in the hardening furnace, are discharged through closed gravity chutes into an oil quench, open end down. Each one drops down over a conical ring of spray nozzles while another set of spray nozzles surrounds it, the whole outfit (one for each of the six lines of

shells) being submerged in a steel tank filled with oil. In this way both internal and external quenching is accomplished effectively and simultaneously. When fully quenched the shells are tipped mechanically and deposited onto a flight conveyor (Fig. 4) which carries them up and onto the charging table of the draw furnace. This quench tank conveyor moves intermittently, in synchronization with the two sets of walking beams, advancing each shell only as the loads in the furnaces are advanced. The operation of all furnace conveyor units is controlled by a timing clock which starts and stops all drives simultaneously at predetermined intervals.

The hardening furnace is 18 ft. long and 5 ft. wide inside, and 18 in. high from rail top to spring line of arch. Side walls and arch are of 9-in. insulating firebrick backed by 2½ in. of insulation. The bottom consists of 5 in. of insulating firebrick and 7½ in. of insulation. Sillimanite cement coating covers the entire interior of the furnace brickwork.

For heating the quenching furnace, gas burners of the low pressure type are mounted in the side walls; they fire both above and below the work, 34 burners in all. Each burner has a block, block-holder, valve and gage. This system operates with air at 1¼ lb. and gas at 4 to 6 in. water pressure. Fuel consumption is in the neighborhood of 4000 cu.ft. of 530-B.t.u. gas when heating at the rate of 2600 lb. of net work per hr. to a temperature of 1600° F. A single blower furnishes air to both furnaces. Burners are manifolded into groups and each group of not more than five burners is provided with an individual automatic gas-air proportioner with a zero governor for the gas. In addition, the gas-air ratio can be adjusted manually at each inspirator. Automatic temperature control with necessary pyrometers and recorders is provided. The automatic gas-air proportioner can also be adjusted manually at each inspirator.

Fig. 6 — Discharge End of Shell Drawing Furnace



The quench tank is of welded steel, holds 8000 gal. and is sunk in the floor to allow space for the shells to drop down into it from the high heat furnace. A pump forces oil through the spray nozzles. Temperature of the oil is maintained automatically by the use of banks of water pipes in another steel tank of 8000 gallons capacity. The oil is circulated between these two tanks, and a spray pond is used to cool the cooling water for re-use.

The draw furnace (Fig. 5) is 21 ft. long, 5 ft. wide inside, and the passageway is 18 in. high from rail to underside of upper duct. Walls, arch, and bottom are of substantially the same thickness of insulating firebrick and insulation as those of the high heat furnace, and the same type of walking beam conveying mechanism is employed.

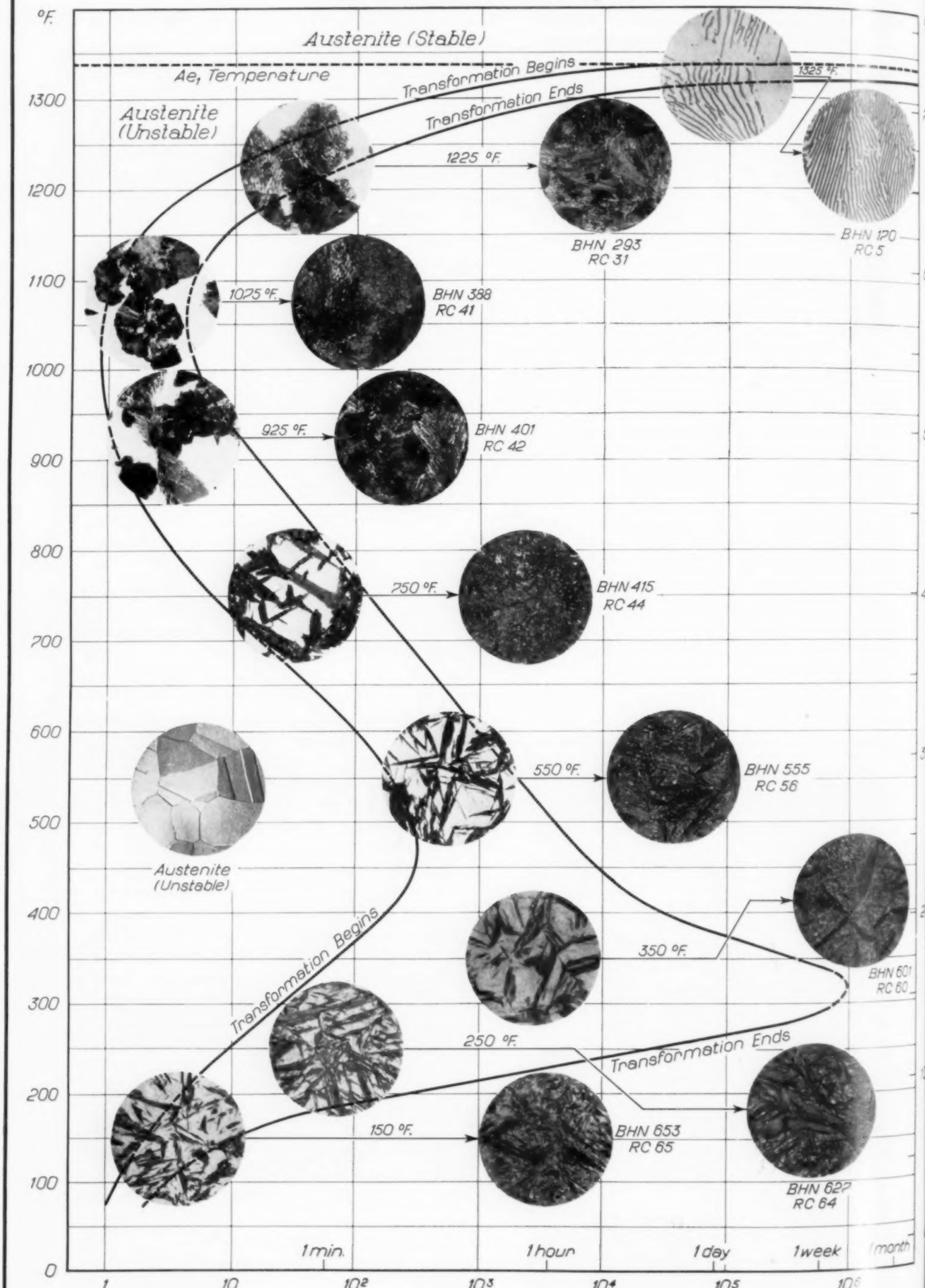
This furnace is of the recirculating hot air type and is equipped with two low pressure air heaters mounted on top. Each heater is provided with single stage, low pressure-velocity type burners, operating on air and gas at the pressures already stated. Heated air is recirculated throughout the furnace by two fans and appropriate ducts. The entry duct is located in the top of the furnace, and the hot gases pass directly into a chamber above the work formed by the arch of the furnace and a perforated chromium alloy plate equipped with dampers. The hot atmosphere passes through this plate, around the work, and out at the bottom through another duct equipped with dampers. Cool gases are then carried to one side of the furnace and up to the combustion chamber for reheating.

The fuel consumption of this furnace is estimated at 1600 cu.ft. of 530-B.t.u. gas when heating at the rate of 2600 lb. of net work per hr. to a temperature of 1100° F.

Electric motors of 5 hp. each drive the walking beams of both furnaces; one of 2 hp. is provided for the quench tank conveyor, and two of 10 hp. each for the recirculating fan.

Transformation of Austenite in 0.78% Carbon Steel

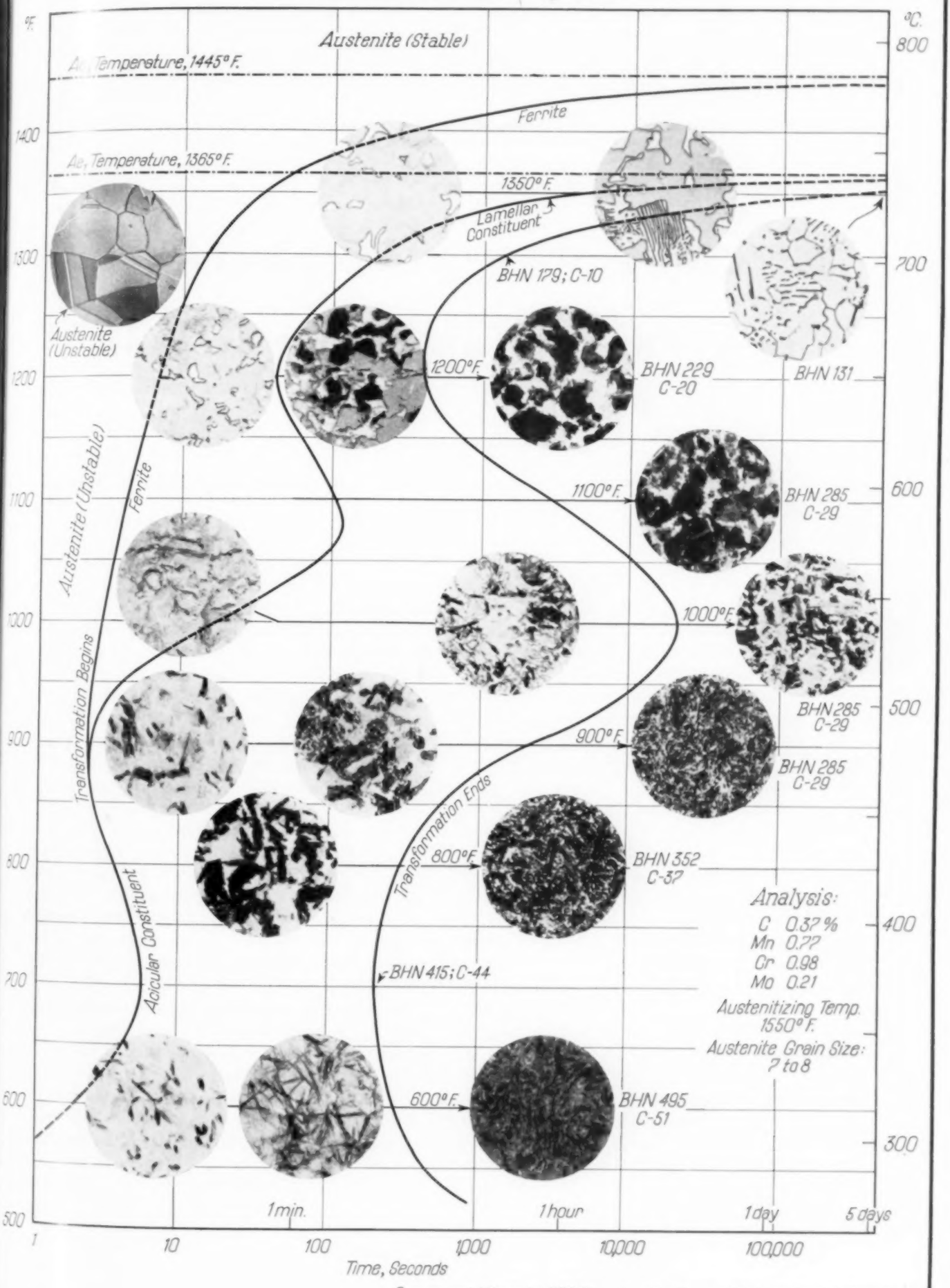
at Constant Sub-Critical Temperature



"S" Curve and Micros (at 600 Diameters) by Research Laboratory, U. S. Steel Co.

Transformation of Austenite in 4140 Alloy Steel

at Constant Sub-Critical Temperature



Curves and Micros (at 600 Diameters) by Research Laboratory, U.S. Steel Corp.

The forthcoming ASM Convention in Philadelphia will feature a Symposium on Controlled Atmospheres on October 23 and 24. The following paper on a very practical aspect of the art of bright heat treatment is scheduled for the first day, but was received too late for preprinting in the usual pamphlet form

Controlling Atmospheres

to Avoid Coloration and Etching

PREVENTION OF OXIDATION is the objective of most applications of controlled atmosphere furnaces for ferrous metals because of the great bulk of low carbon steel which is bright annealed in the form of sheets, strip, tubing, wire, punchings, and stampings. Low carbon steel assemblies are also furnace-brazed for this reason. Furthermore in numerous applications of "bright" hardening, the elimination of scale is the only factor involved. Sintering of pressed compacts of metal powder likewise requires suitable protective atmospheres.

Sometimes the minimizing rather than the complete elimination of oxidation is of value where this is the best that can be hoped for — as in the annealing of stainless steel stampings for kitchenware and refrigerator evaporators.

The first — although not the only — requirement of a protective atmosphere for preventing or minimizing oxidation of ferrous metals is that it be free of uncombined oxygen. Most furnace atmospheres are mixtures of various gases, some of which contain combined oxygen, yet they can easily be so proportioned as to render ineffective the objectionable constituents and obtain the advantages of the desirable ones.

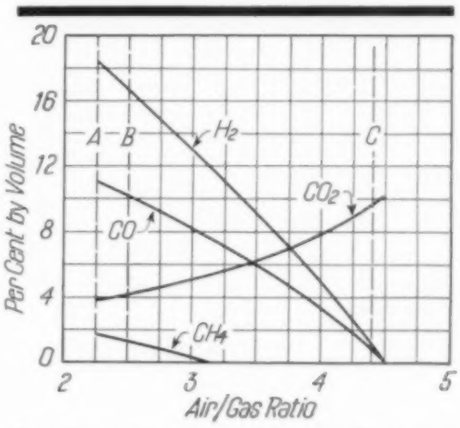
By far the most common atmosphere employed is that formed by the partial combustion of hydrocarbon gases, such as coke oven gas, natural gas, propane, or butane. Because water vapor is produced in objectionable quantities when hydrocarbons are burned, it is not practicable to use the heat source of a fuel-fired furnace simultaneously as an atmosphere source, if oxidation of the ferrous metals is to be avoided. As a result, the atmosphere gas must be produced in a separate, self-contained unit arranged to remove a large portion of the water vapor. The heat source, if gaseous fuel is used, is then separated from the furnace atmosphere by the use of radiant tubes or muffles. If electric heat is used, the resistors can be exposed to the atmosphere and will radiate their heat directly to the work.

The products of partial combustion of hydrocarbon gases (insufficient input air to give complete combustion being used) make atmospheres consisting of mixtures of carbon dioxide, carbon monoxide, methane, nitrogen, water vapor, and H_2S and SO_2 if the fuel contains sulphur. An analysis of a typical atmosphere so produced from coke-oven or natural gas would be 5.0% CO_2, no oxygen, 10.0% CO, 15.0% H_2, 1.0% CH_4, and the remainder nitrogen. As will later be explained at some length, it is generally desired to keep the ratios $H_2O \div H_2$

By A. G. Hotchkiss and H. M. Webber
Industrial Heating Section
General Electric Co.
Schenectady, N. Y.

and $CO_2 \div CO$ as low as possible in order to minimize the oxidizing tendency of H_2O and CO_2 and to emphasize the reducing effect of H_2 and CO. This condition is favored by operating the "converter" (the device for generating the gas for the protective atmosphere) with the lowest possible amount of air. To produce oxygen-free atmospheres from low ratios of input air and raw gas, it is necessary that the air and gas be completely mixed and that burners and combustion chamber of proper design be used. Firing into refractory beds materially aids the completion of the gas reactions.

The first diagram shows the result of such "partial combustions" — how the hydrogen and carbon monoxide decrease and the carbon dioxide increases as the ratio of input air to gas increases. It also illustrates the desirability of operating the machine on a low ratio in order to keep at the left side of the chart. The content of water vapor in the furnace atmosphere is controlled by passing these products of partial combustion through a surface cooler, where moisture is condensed out generally to a dew point 10° higher than the temperature of the cooling water employed.



Gas From an Atmosphere-Gas Converter Is Largely Nitrogen. Above curves show remaining constituents for various ratios of input air to fuel gas (coke oven gas)

A — Reducing mixture for brazing and scale-free hardening; flammable.

B — Reducing mixture for bright annealing or normalizing steel; this mixture is flammable.

C — Inert mixture for bright annealing copper; non-flammable.

(The dew point of a gas in degrees Fahrenheit, rather than the percentage of its water vapor, is commonly expressed because of the relative ease with which a dew point can be determined. For example, gas can be passed over a mirror equipped with a controllable means of cooling, and the temperature at which the moisture condenses on the mirror can be measured readily by a thermocouple and potentiometer. This temperature is its dew point. Content of water vapor is determined from appropriate tables or from the alignment cards on pages 570 and 571.)

In many cases, a surface cooler gives sufficiently low water vapor and a favorable ratio of H_2O to H_2 to produce bright work after heat treatment therein. But if the atmosphere-gas converter is incapable of producing sufficient hydrogen, or if the cooling-water temperature is so high as to fail to condense out enough of the water vapor — and particularly if the metallic charge in the heat treating furnace is very heavy and cools slowly through a low-temperature critical oxidizing range — it may be necessary to remove additional water vapor by low temperature refrigeration or by absorption dryers.

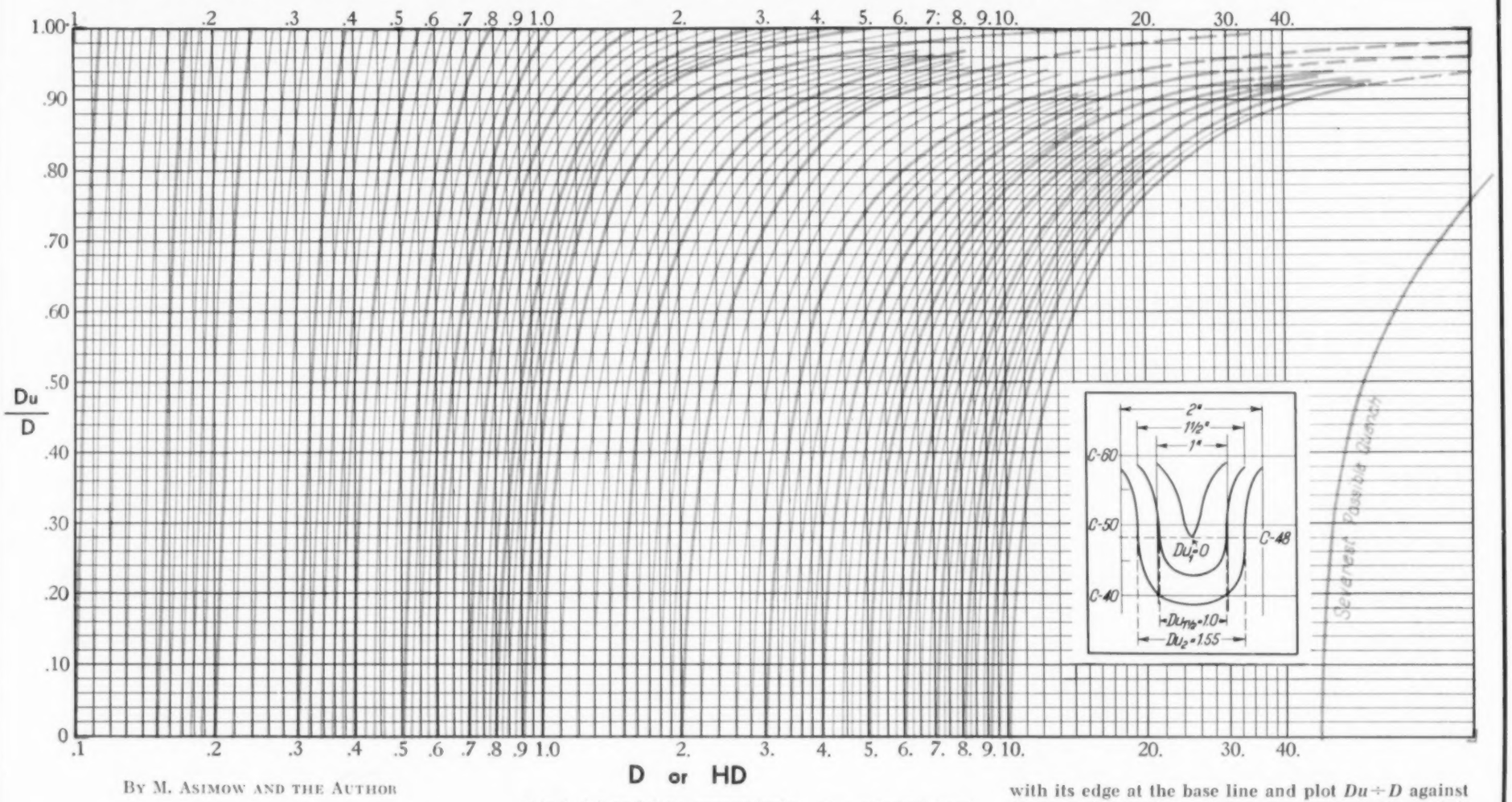
The equilibrium curve for iron, H_2O, and H_2, shown dotted in the second diagram, page 521, indicates that it would be possible to have a high content of water vapor at high temperatures without oxidizing iron. But if this same ratio of H_2O to H_2 were maintained during the cooling cycle, the steel would blue or oxidize at low temperature, the intensity of which would be determined by the cooling rate (time available). For example, if the gas mixture quoted toward the bottom of page 518, which contains 15% H_2, also should contain 3.7% H_2O, then the ratio of $H_2O \div H_2$ would be approximately 0.25. At 1200° F. this point is at b', and is well within the reducing range. However at 975° F., we cross the equilibrium curve and enter the field of oxidation.

If the atmosphere contains nothing but H_2 and H_2O in the above proportions, it would be impossible to cool the steel below 975° F. without oxidizing its surface somewhat. But if we have a complex gas containing also CO and CO_2, such as that obtained from the partial combustion of hydrocarbon gases in general use today, the situation changes. The theoretical equilibrium curve for iron, CO, and CO_2 (full line) has the opposite slope, crossing the other at about 1500° F. Therefore, with 5% CO_2 and 10% CO in the gas as well as the hydrogen and water vapor, the ratio of the carbon gases (0.50, plotted as B'—B) shows this pair of gases to be reducing, and increasingly so as the temperature decreases.

It is therefore possible with this complex gas to cool steel down through the range below 1000° F. without oxidation because the reducing

Cooling Power of Quenching Baths

Curves whereby severity of quench (heat transfer equivalent H) can be estimated. *Copyright, 1939, Carnegie-Illinois Steel Corp.*

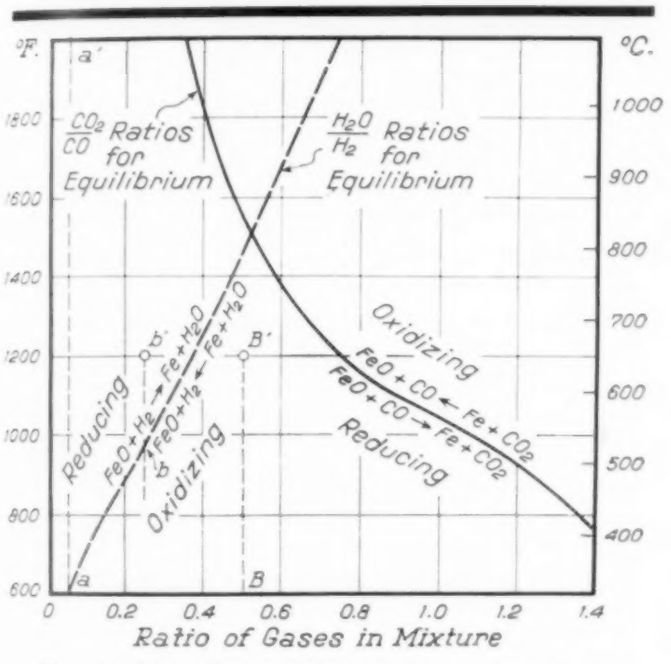


By M. Asimow and the Author

To use this chart, harden *at least* three bars of various diameters in the given medium at working temperature and circulation, and determine curves of hardness distribution, edge to axis, at mid-length. In the example sketched in the inset above, D is 1, 1.5 and 2 in. respectively. At a selected hardness horizontal, as C-48, which intersects or touches all curves, determine the ratio $Du \div D$ between soft center and bar diameter. (Soft center diameter Du is 0, 1.0 and 1.55 in.; $Du \div D$ is 0, 0.66 and 0.77 respectively.) Lay a piece of tissue paper over the chart with its edge at the base line and plot $Du \div D$ against D for each bar size. Slide tissue paper right or left until these points fall on a single curve, which for this quench happens when D_1 is at 5.0 and $D_{1.5}$ is at 7.5 (these now being values of HD). Then H, the severity of this quenching set-up, is $HD \div D$ or $5.0 \div 1.0$ or 5.0 (or $7.5 \div 1.5$ which gives the same result).

effect of the CO_2/CO combination overcomes the oxidizing effect of the H_2O/H_2 combination. In general, the atmosphere whose analysis has been quoted should have a dew point of +70° F. or less for annealing in a bell furnace with a slow-cooling cycle, but the dew point might be +90° F. or more in a continuous furnace with relatively fast cooling and still produce bright surfaces.

The ratio of CO_2 to CO existing in the gaseous mixtures commonly used for annealing steel is almost always favorable to a bright product. But etching — evidenced by a gray matte finish on the surface of polished steel



Theoretical Equilibrium Relations Between Iron, Oxide, Hydrogen and Steam and Between Iron and the Two Carbon Oxides at Heat Treating Temperatures

annealed in batches — occurs in the 1000 to 1200° F. range if the CO content is too high and the H_2O is too low — that is, if their amounts are too far from equilibrium with the CO_2 and H_2 in the mixture.

In other words, a *small amount* of water vapor is required in these complex mixtures to maintain equilibrium between the component gases when they are at high temperature, otherwise the component gases will tend to dissociate and recombine to establish equilibrium, the necessary water vapor being formed as a product. The steel acts as a catalyst for the reactions, and its surface becomes roughened in the process. This effect has been explained in detail by A. L. Marshall in a paper in *Transactions* ASM, 1934, p. 605, entitled "Bright Annealing of Steel in Mixed Gas Atmospheres". A paper in the ASM Symposium on Controlled Atmospheres, 1941 by J. B. Austin and M. J. Day entitled "Chemical Equilibrium as a Guide in the Control of Furnace Atmospheres" may also be consulted with profit.

Although sulphur in the furnace atmosphere will discolor non-ferrous metals (an action which is sometimes confused with oxidation) it has no harmful effect on bright steel when encountered in the usual quantity. However, if the sulphur content of the hydrocarbon gas exceeds about 30 grains per 100 cu.ft., enough of this sulphur should be removed to reduce it to a point below this value, in order to avoid both discoloration of the work and corrosion of the metallic parts handling the hot atmosphere and of the heat resisting alloy and electrical resistors in the furnace.

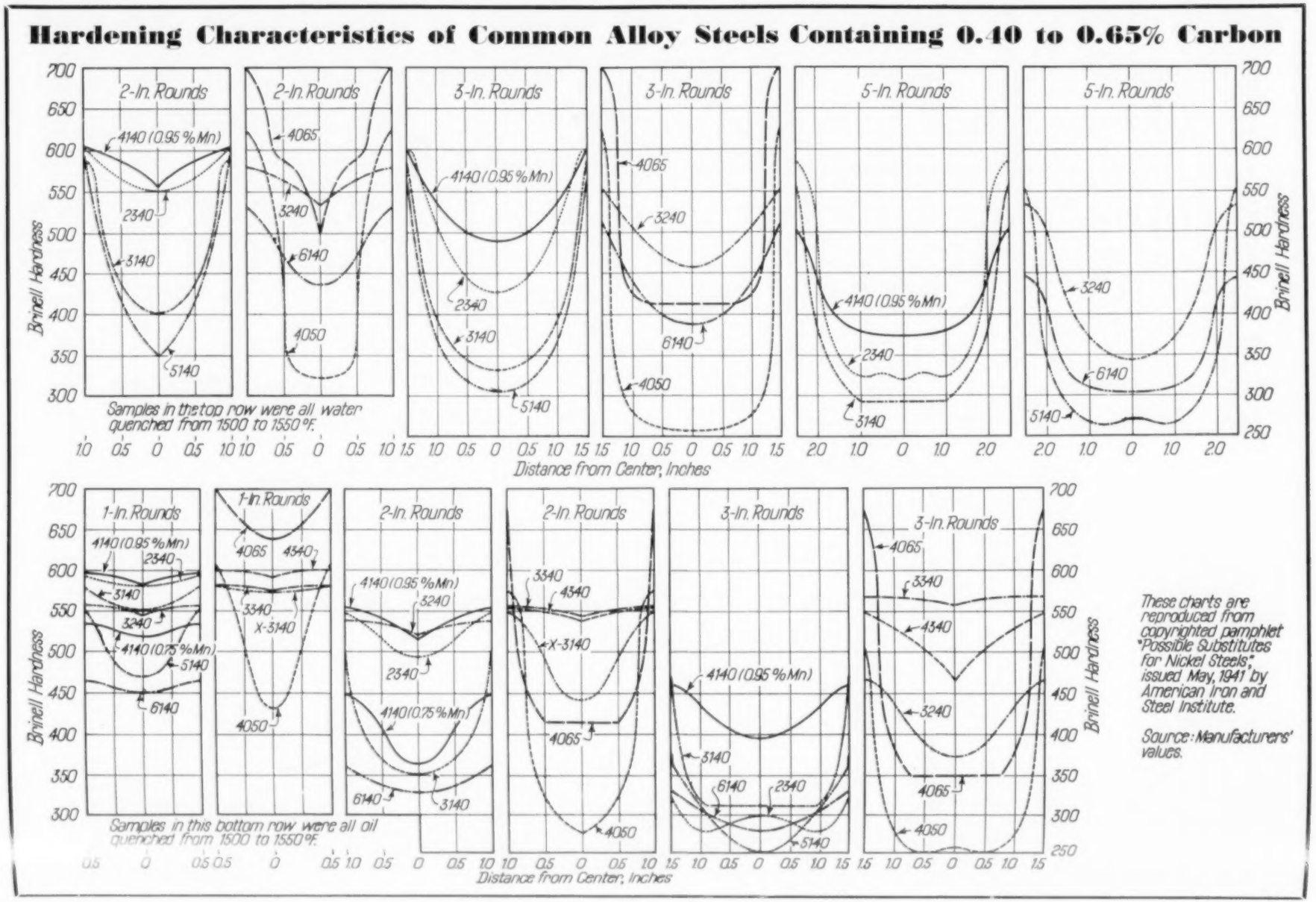
Dissociated Ammonia

Another mixture of gases sometimes used for preventing oxidation is dissociated ammonia, which is formed by cracking anhydrous ammonia over a catalyst, at high temperature. This mixture consists of 75% hydrogen and 25% nitrogen, by volume, with extremely small amounts of water vapor and undissociated ammonia as impurities. Because of its very favorable ratio of H_2O to H_2, this is an excellent gas for bright annealing, both from the standpoint of preventing oxidation (and also preventing reduction in the form of decarburization).

Dissociated ammonia has been used in the bright annealing of high carbon steel in coiled strip, and in the strand annealing of chromium-nickel alloy wire and narrow strip. The latter application requires the removal of the last traces of water vapor and ammonia by means of absorption dryers. Specially designed air-tight retorts inside the furnaces and outside fittings are also necessary to maintain a high degree of purity in the atmosphere.

Purification steps are necessary to prevent the formation of selective chromium oxides, which are produced readily by CO_2, O_2, CO, or H_2O, and which, when once formed, are not

Hardening Characteristics of Common Alloy Steels Containing 0.40 to 0.65% Carbon



These charts are reproduced from copyrighted pamphlet "Possible Substitutes for Nickel Steels," issued May, 1941 by American Iron and Steel Institute.

Source: Manufacturers' values.

readily reduced. For example, an alloy steel containing 1.0% of chromium, annealed in the ordinary atmosphere quoted at the beginning of this article as suitable for low carbon steel, will become slightly discolored. Increasing amounts of chromium will result in more pronounced oxidation. However, with a highly purified atmosphere and a suitably constructed furnace, chromium-iron alloys can be annealed and still retain their bright finish.

Dissociated ammonia is sometimes modified for use as furnace atmospheres by burning it more or less completely with air in an atmosphere-gas converter. The resulting hydrogen-nitrogen mixture has a hydrogen content ranging from 30% to 1%, depending on the air-gas combustion ratio. The advantages of the gas are lower cost per cubic foot — due to its dilution with atmospheric nitrogen — and reduced flammability.

Hydrogen is used to a limited extent for atmospheres in small furnaces, such as those for bright annealing chromium-nickel alloys in strands and those for furnace-brazing tungsten carbide tools. For the former, it has to be purified of water vapor and oxygen to prevent selective oxidation of the chromium.

Nitrogen is also used as a furnace atmosphere at times, but not for bright work in large furnaces, because of the difficulty of maintaining sufficient freedom from oxygen and oxidized gases. Since nitrogen is inert, it logically follows that to prevent oxidation the nitrogen must be pure and dry, and the construction of the furnace equipment must be adequate to maintain this purity. Silicon steel sheets and strip are annealed at high temperatures (approximately 1900° F.) in such an atmosphere, since brightness is not important to the product.

Detecting the Source of Discoloration

Clean, bright steel entering a controlled atmosphere furnace sometimes emerges discolored, and it is necessary to do a little detective work to learn the cause.

Oxidation can be divided roughly into two classes — that produced at low temperature in the bluing range below 900° F., and that produced at higher temperatures.

In the low temperature range, either oxygen or water vapor can produce oxidation or discoloration of the same appearance. Such discoloration generally takes place during the cooling cycle. Gas analysis and dew point measurements will aid in determining which impurity is causing the trouble.

Oxidation at high temperature generally goes beyond the bluing stage and results in etching or scaling. Oxygen tends to produce a light-gray to black, dull-appearing scale which loosens upon cooling, while excessive moisture produces a tighter oxide with a darker (sometimes shiny) appearance.

The position in the furnace at which oxidation occurs may be determined by examining the product. For example, if steel parts emerging from a continuous furnace have a bright but etched or roughened surface, it indicates that oxidation from some source has occurred near the front of the furnace during the heating-up period, followed by reduction of the oxide and proper protection from further oxidation during the cooling cycle.

One method of determining the cause of oxidation is to put a test piece of bright copper through the furnace with the steel. Copper is oxidized by O_2 but not by H_2O, so its behavior as compared with that of the steel should give a good clue as to the culprit. One should not be misled, however, by a sulphur discoloration which might be mistaken for oxidation. Fortunately, these two types of discoloration can be identified, since the oxide is readily pickled off by dilute sulphuric acid, while the sulphur discoloration is not.

If oxygen is thought to be the offender, it is logical to look for air leaks in gaskets, welded joints, pipe connections, or around the doors (especially below the hearth level). Sometimes, in continuous furnaces, extra gas is supplied to counteract the tendency of drafts in the room to blow air into the cooling chamber.

If water vapor is the offender, the surface cooler of the atmosphere-gas converter should be examined to learn whether it is functioning properly. Also look into the condensate trap or pipe lines to make sure that they are not filled with water. The cooling chamber of a continuous furnace should be checked to make certain that it is warm enough to prevent condensation of water vapor on the inner lining. Such moisture might subsequently be vaporized by the hot work, and discolor or scale it. Terminal stuffing boxes in the heating chamber, gaskets, and room drafts should be checked to see that infiltering air, which combines with the hydrogen at the high temperature to form water vapor, is eliminated or minimized.

In batch annealing of heavy loads, discol-

Metal Progress, 1941 Reference Issue, Page 523

Hardness Conversion for Hardened Steels

By Howard Scott and T. H. Gray, Westinghouse Electric & Mfg. Co.

Diamond Pyramid Hardness 50-kg. Load	Rockwell Hardness: C-Scale-150 kg. Brale Penetrator	Rockwell Hardness: A-Scale-60 kg. Brale Penetrator	Rockwell Superficial (From Wilson Mechanical Instrument Co. Chart No. 38): 15-N Scale	30-N Scale	45-N Scale	Scleroscope Hardness	Monotron Load Scale Value (9 Divisions)	Brinell Hardness 10-mm. Ball, 3000-kg. Load: Tungsten Carbide Ball: Hardness Number	Tungsten Carbide Ball: Diameter in mm.	Hultgren Ball DPN 940: Hardness Number	Hultgren Ball DPN 940: Diameter in mm.	Steel Ball DPN 900 (From A.S.M. Metals Handbook, 1939 Ed., p. 115): Hardness Number	Steel Ball DPN 900 (From A.S.M. Metals Handbook, 1939 Ed., p. 115): Diameter in mm.	Approximate Tensile Strength of Steel
DPH	R_C	R_A	15-N	30-N	45-N	Scl.	Mon.	BHN	mm.	BHN	mm.	BHN	mm.	T.S. x 10^3
250	20	58	68	42	20	32	26	192	4.35	207	4.20	201	4.25	100
		60	70	44		34	28	197	4.30	212	4.15	202	4.20	
						36	30	202	4.25	217	4.10	212	4.15	
		62	72	46	24	38	32	207	4.20	223	4.05	217	4.10	
	25			48	26	40	34	213	4.15	229	4.00	223	4.05	
		64	74		28	42	36	219	4.10	235	3.95	229	4.00	110
300	30			50	30	44	38	224	4.05	241	3.90	235	3.95	
	32	66	76	52	32	46	40	230	4.00	248	3.85	241	3.90	
	34	67	77	54	34	48	42	235	3.95	255	3.80	248	3.85	
350	36	68	78	56	36	50	44	241	3.90	262	3.75	255	3.80	120
	38	69	79		38	52	46	248	3.85	269	3.70	262	3.75	
	40	70	80	58	40	54	48	255	3.80	277	3.65	269	3.70	
400		71	81	60	42	56	50	263	3.75	285	3.60	277	3.65	130
	42	72	82	62	44	58	52	270	3.70	293	3.55	285	3.60	
	44				46	60	54	277	3.65	302	3.50	293	3.55	
450	46	73	83	64	48	62	56	284	3.60	311	3.45	302	3.50	140
		74	84	65	50	64	58	292	3.55	321	3.40	311	3.45	
	48			66	51	66	60	301	3.50	331	3.35	321	3.40	150
500		75	85	67	52	68	62	310	3.45	341	3.30	331	3.35	
	50	76		68	53	70	64	320	3.40	352	3.25	341	3.30	160
			86	69	54	72	66	330	3.35	363	3.20	352	3.25	
550	52	77		70	55	74	68	340	3.30	375	3.15	363	3.20	170
			87	71	56	76	70	351	3.25	388	3.10	375	3.15	
	54	78		72	57	78	72	362	3.20	401	3.05	388	3.10	180
600			88	73	58	80	74	374	3.15	415	3.00	401	3.05	
	56	79		74	59	82	76	387	3.10	429	2.95	415	3.00	190
650			89	75	60	84	78	400	3.05	444	2.90	429	2.95	
	58	80		76	61	86	80	414	3.00	461	2.85	444	2.90	200
			90	77	62	88	82	429	2.95	477	2.80	461	2.85	
700	60	81	90.5	78	63	90	84	444	2.90	495	2.75	477	2.80	210
	61		91	79	64	92	86	459	2.85	514	2.70	495	2.75	
750	62	82			65	94	88	476	2.80	534	2.65	514	2.70	220
	63		91.5	80	66	96	90	494	2.75	555	2.60	534	2.65	
800	64	83		81	67	98	92	515	2.70	578	2.55	555	2.60	230
	65	83.5	92	82	68	100	94	534	2.65	603	2.50	578	2.55	
850	66	84		83	69	102	96	554	2.60					240
	67	84.5	92.5	84	70	104	98	575	2.55					
900	68	85	93	84.5	71	106	100	598	2.50					250
	69	85.5		85	72	108	102	623	2.45					
950		86	93.5	85.5	73	110	104	650	2.40					260
1000	70	86.5	94	86	74	112	106	678	2.35					
	70.5				75	114	108	708	2.30					270
					76	116	110	740	2.25					
					76.5		112							280
					77		114							
					77.5		116							290
														300
														310
														320

Thickness of Stock Required for Accuracy
(Ten Times the Depth of Impression in Inches)

DPH	DPH (10 kg)	DPH (50 kg)	R_C	15-N	45-N	BHN
200	0.017	0.038	0.072	0.015	0.040	0.186
300	0.014	0.031	0.059	0.012	0.032	0.135
400	0.012	0.027	0.050	0.009	0.026	0.098
500	0.011	0.024	0.044	0.007	0.022	0.080
600	0.010	0.022	0.038	0.006	0.018	0.068
700	0.0092	0.020	0.033	0.005	0.016	—
800	0.0086	0.019	0.030	0.004	0.013	—
900	0.0081	0.018	0.027	0.003	0.012	—
1000	0.0076	0.017	0.025	0.003	0.010	—

Monotron tests at all hardnesses can be made on 0.018-in. stock. Scleroscope numbers vary with size; relations given are for 1-in. pieces.

In operating any test machine, follow manufacturer's instructions and check frequently against test blocks. Major causes of discrepancy: *(a)* decarburized skin, *(b)* specimens too thin, *(c)* off-standard indenters, *(d)* inaccuracy of machine.

Above conversions are for steel, irrespective of composition and structure, up to its maximum hardness, and for any other material having about 30,000,000 psi. elastic modulus, uniform in depth to bottom of impression. (An exception is that Rockwell test values for shallow hardened steel may be 1 or 2 points higher than by conversion from DPH.) For sintered carbides (DPH 900 to 1700) with much higher modulus the relations between DPH and Rc may be computed from $\text{DPH} = \frac{2.445 \times 10^6}{(\text{B} - \text{Rc})^2}$ wherein constant B is 118 for carbide (120 for steel).

oration may occur in the summer as the result of an increase in cooling-water temperature in the surface condenser of the converter. The effect of this would be to increase the H_2O in the atmosphere with no increase in H_2 to compensate for it, and slow cooling through the critical bluing range may result in discoloration. In this event, installation of a refrigerated cooler will probably reduce the water vapor in the gas to a point where bright annealing can again be obtained.

Parts that are being hardened scale free from controlled atmospheres by quenching from the discharge end of a conveyor through a chute sealed in oil (in order that contact with the air will be avoided) are generally free from oxidation. Sometimes, however, they are found to be discolored. This discoloration may be a carbon film or it may be a film of dirt resulting from heavy oil or dirt that was on the parts before they were placed in the furnace. This sludge deposit can usually be rubbed off, leaving a bright surface.

Surface Colors Obtained by Quenching Carbon Steels in Mineral Oil Containing Water or Air as Impurities

Thickness of Sample	Volume % Water in Quenching Oil				Air in Oil
	0.005	0.05	0.20	0.5★	
0.010 in. 0.040 ↓ 0.125 0.250 0.50 0.75	Bright Straw ↓ to ↓ Blue	Bright Deep Straw ↓ to ↓ Deep Blue	Bright Blue ↓ to ↓ Blue Black	Straw Deep Blue ↓ to ↓ Dull Black	Bright Bright ↓ Straw ↓ to Deep Straw

★At this concentration the oil changed from its natural color to a brick-red color.

A discoloration that is a true oxide film is caused by either water or air in the quenching oil. A series of tests given in the attached table on plain carbon steel quenched in mineral oil indicated that discoloration caused by water or air, or by both, increases with the cross-section of the piece and with the temperature at which the work is quenched.

This discoloration from the quench may be uniform, it may appear as splotches or it may be on only one side of the piece. Water is the cause of most discolorations and may come from condensate or leaks. Air sometimes enters through packings on circulating pumps and appears as foam on the surface of the oil. Water can be removed by boiling the oil and circulating it to allow the steam to escape.

If carbon steel parts are clean when they are placed in the furnace, if the atmosphere within the furnace is right, and if the quenching oil is clean and free from air and water, even those of heavy section can have perfectly bright surfaces after hardening. It must be remembered, however, that alloy steels with 1% or more of chromium will be dark after treatment in the normal protective atmosphere.

Discoloration After Treatment in the Furnace

Metals coming from controlled atmosphere annealing or brazing furnaces are usually bright and dry, and free from any protective oil coating which they might normally have otherwise. This leaves them vulnerable to subsequent attack by the water vapor, oxygen, and impurities in the air. Accordingly, it is customary to see that they go immediately into the next step of production and that they are soon given a protective coating of oil or a suitable surface finish.

In a few cases the work is deliberately discolored as it emerges from the furnace in order to provide an oxidized finish which has a reasonably good resistance. Bright steel tubing that is subsequently passed through a bluing oven is a typical example. In other instances, malleable castings are discharged from the furnace while so hot that they will oxidize. The latter arrangement, although lacking the refinements of control of the bluing oven, saves considerable floor space.

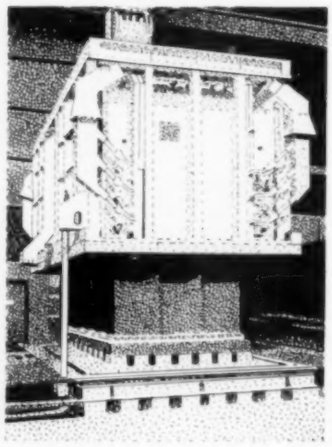
Lubricants on Work

Metals which have been processed prior to being placed in controlled atmosphere furnaces are generally coated with lubricants, such as oil, grease, soap, or lime. It is generally best to remove these lubricants before charging the parts into the furnace. Discoloration from these lubricants is sometimes confused with oxidation and, therefore, this subject deserves separate consideration.

All lubricants decompose at the high temperatures of heat treatment. If the lubricant is not sufficiently volatile to pass off in the furnace atmosphere, it is likely to leave a deposit

on the heat treated work. This might necessitate a subsequent cleaning operation; in such cases it is obviously better to do the cleaning before the work enters the furnace.

Sometimes one may choose a grade of lubricant which has suitable lubricating characteristics and, at the same time, is sufficiently volatile not to impair the surface finish as the work passes through the furnace. For example, the oil is usually partially removed from cold-rolled steel strip by passing the strip through carpet wipers, air blasts, or some similar arrangement. The remaining film is usually innocuous on coils. On the other hand, stampings made therefrom which are to be bright annealed or furnace brazed are generally given a caustic wash or other degreasing treatment to remove lubricants completely.



Gas Consumption

Furnaces using controlled atmospheres have a number of construction features not incorporated in furnaces open to the air. These are essential to prevent loss of gas and to minimize entrance of air which would upset the control established by producing the desired atmosphere in a separate unit.

For example, bell type furnaces are equipped with seals filled with water, oil, sand, shot, or chrome ore. Casings of controlled atmosphere furnaces are welded gas-tight, and their top plates, if removable, have gasketed or pitch seals. Furnaces charged and discharged from the ends have flame curtains to supply velocity barriers and to burn out oxygen from infiltering air; they sometimes also have asbestos curtains and exhaust hoods over the doors. Doors fit snugly by means of sloping fronts with ground surfaces, or by wedging devices or clamps. Stuffing boxes are provided where heating element terminals, radiant tubes, and door-lifting rods pass through the furnace casing. The joints between the heating chamber and the cooling chamber sections are welded gas-tight or fitted with gaskets.

Vestibules or front extensions are frequently employed to provide air-locks which can be purged readily. Furnaces are sometimes charged and discharged from underneath by means of elevators to keep the light gas in and the heavy air out. Bearings for roller hearths must be installed gas-tight. If there is more than one opening in the furnace, they must be at the same level to avoid a chimney effect which would draw air in. If drafts in the room are excessive, the furnace must be blocked off at the ends by screens or be completely enclosed. End doors may be mechanically operated for fast action in order to minimize the intervals during which they are open, and they are usually interlocked in such a way that only one door can be open at a time.

After the designer has taken all these factors into account, he generally relies on the experience gained from former installations to estimate the gas consumption for the furnace atmosphere. He also takes into account special factors relating to the individual problem at hand. For example, additional gas is sometimes required to purge out vapors from oil on the work that is being annealed or from carbonaceous binders used in parts that are being sintered. In furnaces with large door openings, loss of the entire atmosphere may be expected each time the door is open. Hence, sufficient atmosphere-producing capacity should be provided to purge the furnace quickly, so that there will be a good atmosphere around the work by the time the work gets hot. In general, it takes four to five volume changes to purge a chamber effectively. In estimating the atmosphere consumption of bell furnaces with sand seals, provision for a loss of 5 cu.ft. per hr. per lineal ft. of seal is often made.

Heating and Cooling Methods

Since practically all heat treatments of ferrous metals are at relatively high temperatures, radiant heating is by far the most effective method of conveying the heat from the source to the work. In most designs convection heating seldom plays an important role. Electric resistors or radiant tubes are mounted inside the furnace in such a way as to radiate their heat directly to the work; muffles are also sometimes used to separate the heat source from the relatively stagnant atmosphere.

(Continued on page 536)

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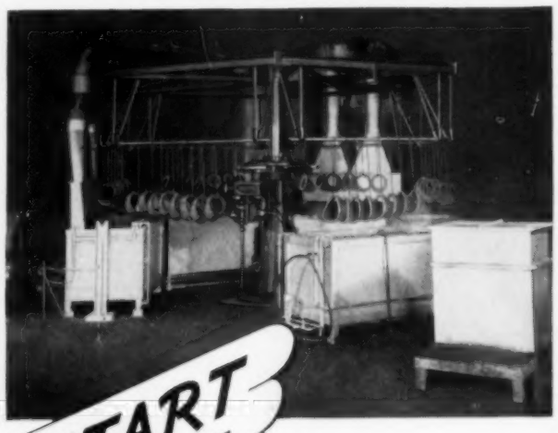

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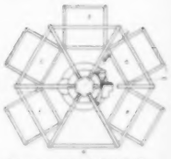


FULL-AUTOMATIC, COMPACT

Atmospheres

(Continued from page 526)

Several methods are used for cooling the work, the choice depending upon the type of furnace and the metallurgical treatment involved. Most continuous furnaces have water-jacketed cooling chambers, 2½ to 4 times as long as the heating chamber, depending upon the nature of the work with respect to its ability to give up its heat by convection. This, no doubt, plays the most prominent part in the cooling cycle. If it is desired to minimize the rate of cooling at the high temperature end of the cycle, an insulated cooling section is sometimes installed adjacent to the heating chamber, followed by water-jacketed sections. If work is to remain bright after it leaves the cooling chamber, it should emerge to the outer atmosphere no hotter than about 300° F.

Bell type furnaces are commonly equipped with fans in the bases to circulate the atmosphere in order to shorten the cooling cycle and minimize the number of bases required. Water sprays are played on the outside of the retorts to take the heat away as fast as it is given up by the work inside them. Sometimes water is directly sprayed on work traveling through continuous furnaces, care being taken to see that the work emerges at a temperature above 200° F. so it may dry itself.

In order to accelerate the cooling of work within a heating chamber of a batch type furnace after the heat is cut off, a recirculating system is sometimes employed, by means of which the hot gas is drawn from the chamber through an external surface cooler and blower and forced back into the chamber. This greatly improves the normal rate of cooling and increases the capacity of the furnace.

Retarding the rate of cooling of a stack of high carbon steel coils within a retort is accomplished (after the furnace is removed) by dropping an insulated hood over the retort for a while. Later, this hood is removed and the retort is exposed to the air for air cooling.

Protective atmospheres have been used so successfully in furnaces for the prevention of oxidation that the metal working industry now uses them wherever they are practical. As a result, production is speeded up, quality is improved, and important savings are realized.

Even though the production, per machine, of similar forging equipment approaches twice that of the 1914-1918 period, the principal contribution of the forging industry to the greatly expanded shell program is the ability to make blanks of such accuracy that the cavity needs no machine work

Forging of Shell

EVENTS IN EUROPE which forced a condition of "national emergency" in this country, with the possibility that war may be thrust upon us, has focused considerable attention to the production of shell on a war basis. This, in turn, brings up the question of the ability of American industry to expand its production of shell to the required quantities when necessity should arise. Since foremost among the methods of producing shell bodies is the forging method, the technique of shell forging has been in the limelight during the past year or two, and a number of articles have appeared in the various trade and technical journals describing several methods for their production. Perhaps the biggest question is, particularly in the minds of those who well remember the efforts of the first world war, whether we have made the necessary progress in production methods to avoid the troubles of the past.

Broadly viewed as a projectile, the shell is called upon to serve in one of two basic capacities. It may be used as shrapnel shell where the shell is designed to burst into a great number of pieces, or it may be designed to remain an integral piece for armor piercing prior to explosion for demolition. From the viewpoint of the shell manufacturer, the production problems in either case are much the same, although shrapnel shell has been most discussed, probably because it is used in greater quantity.

Shrapnel shell, in order to obtain maximum fragmentation, must have a uniform metallurgical structure throughout the shell body, for if there are any sections or lines of weakness, the bursting pressure generated by the charge would relieve itself through these points of weakness and cause poor fragmentation. The forged shell offers the desired uniformity of structure. This permits the design of shell which offers maximum effectiveness, based upon the shape as designed and upon the use of the most desirable composition of steel.

During the first world war, shell steels were usually straight carbon steels with the carbon content ranging from about 0.40 to 0.55%, produced by the openhearth process. The necessary physicals were obtained by heat treating the forgings to definite tensile properties which ran a minimum of 90,000 psi. ultimate strength, 45,000 psi. yield point, 20% elongation and 50% reduction. Due to the inability of forging equipment of that period to work to the closer dimensions of today and because a certain amount of warpage was encountered in the heat treating operations, it was necessary to allow a generous amount of metal on all surfaces for machining. The June 1918 issue of *Machinery* lists 68 machining and inspection operations required for the 75-mm. shells of that day. All in all, the forging, heat treating, and machining on all inside and outside surfaces made production slow and expensive.

The more precise metallurgical knowledge in our present period offers a considerable

By Waldemar Naujoks
Chief Engineer
The Steel Improvement & Forge Co.
Cleveland, Ohio

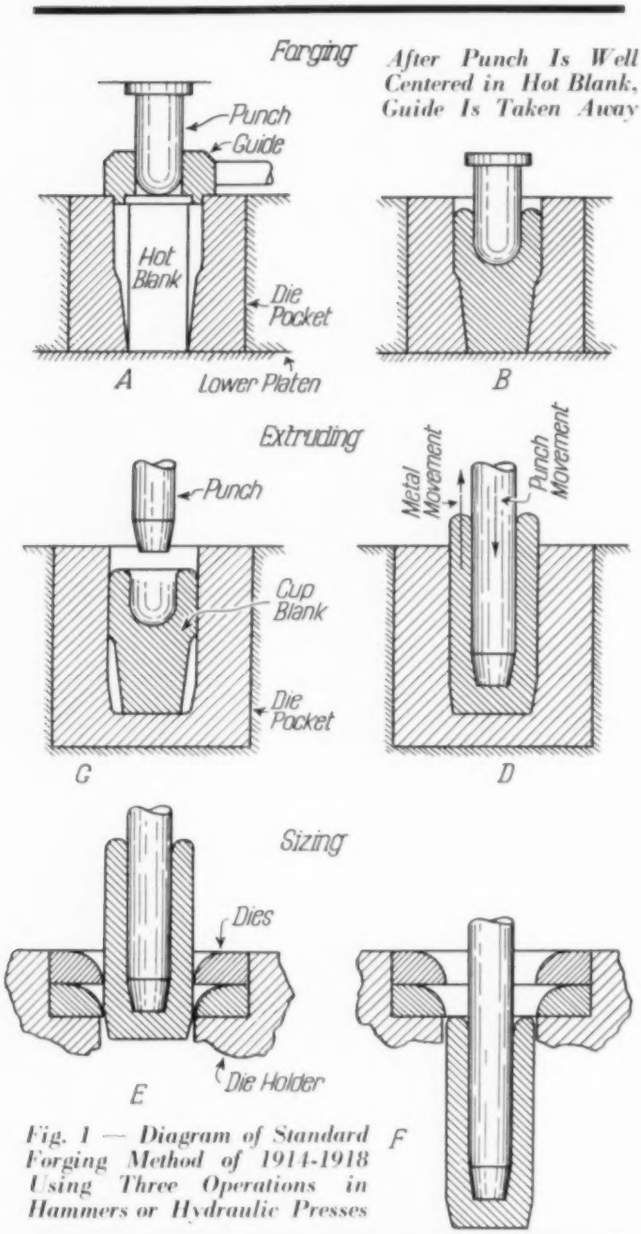


Fig. 1 — Diagram of Standard Forging Method of 1914-1918 Using Three Operations in Hammers or Hydraulic Presses

advantage in the selection and use of steels. Suitable alloying permits better fragmentation properties and eliminates much expensive heat treatment. This, in turn, removes the warpage previously encountered and reduces the amount of stock on the forging necessary for subsequent machining. Metallurgy has studied and taken advantage also of fiber or grain structure in forged steels and present processes incorporate the positioning of the fibers so they serve to the best advantage. For example, the fiber structure in the armor piercing shell can be forged to the contour of the shell nose, and this greatly increases the resistance of the nose to deformation upon the instant of contact.

The position of American industry in its ability to produce for any emergency is best pictured by glancing backward to methods used during the days of 1914-1918. At the start of the World War knowledge of shell forging was quite limited in this country and a considerable period of experimentation and education among industry was experienced before standard methods were commonly adopted. This period also existed among the manufacturers in England and even in France. The basic forging equipment available then was, in general, the same type available today, and this includes the drop hammer, the upsetter, the mechanical press and the hydraulic press. However, the equipment was light and slow in comparison to today's standards and the forging knowledge was much more limited. In addition, the highly developed die and toolsteels of the present day were lacking, together with knowledge and suitable equipment for their use. The forging machine, or upsetter, was not considered or used for shell forgings; the principal method was the use of presses.

Perhaps the commonest method used early in the 1914-1918 period was to prepare a suitable pierced blank in the steam hammer and draw this blank in a press. To do this the heated billet was placed in a die pocket (as sketched in Fig. 1) and the punch guide fitted over the top of the die. The punch was then driven in sufficiently for a start, withdrawn to take away the guide, and then driven in again to the desired depth. The blank or cup was then reheated and drawn to shape in one operation in a large press. This was followed by a sizing operation through draw rings. Later, this three-step method was improved by using presses entirely, generally one press for piercing a blank in one press stroke, and then drawing the shell in a second press in a drawing operation. These methods of course gave a shell with cylindrical exterior, and cavity tapered much or little from nose to base.

The "bulldozer", which is a horizontal type of press with considerable operating room, was also adapted to produce shell, wherein both operations (piercing and drawing) were done in the one machine. Two sets of tools were incorporated so that one set of punches could cool off while the other set was in production.

By 1918 a number of other methods had also been tried. Perhaps the most used method eventually required two presses. The 75-mm. shell, which offers a standard of comparison,

Toolsteels for Hot Working Iron and Steel

By H. E. Replogle, Universal-Cyclops Steel Corp.

Requirements for All Hot Work Tools:

1. Of sufficient toughness to resist working stresses.
2. Of such composition and in such heat treated condition as to resist softening when in service.
3. To have adequate wear resisting properties to assure normal, economical life.
4. Of such composition and heat treated condition as to wholly or partially resist the tendency towards heat or fire checking.

Influence of Design:

1. Wedge designs, sharp corners and thin sections promote chances of breakage and require inherently tougher compositions, usually secured through lower total alloy content steels.
2. Designs including raised sections partially or wholly buried in hot metal require types of higher red hardness and may not require as high toughness characteristics as other wedge designs.

Importance of Mechanical Set-Up:

1. All forging dies should be properly lined up.
2. Machines should be true to assure uniform application of pressure or impact.
3. Dies should be so adjusted in hand fed and automatic forging machines as to prevent excessive pressure being developed on the faces of the dies, thus decreasing probability of fatigue failures.
4. Dies should not be mounted in worn or warped shoes or holders.

Importance of Adequate Preheating:

1. Well warmed dies and tools are less susceptible to cracking.
2. Minimum temperatures secured through use of buried unit heaters in certain types of drop forging dies prolong service life and retard heat checking.

Importance of Cooling:

1. Methods of cooling—Air, Oil, Water. Retards localized heating which may exert a tempering and softening action.
   - a—Air cooling least drastic—applicable to all types of tools. Also serves to blow away scale which, if present, will cause undue wear of dies.
   - b—Oil cooling—somewhat more severe and rapid but rarely detrimental to any tool or die.
   - c—Water cooling—most effective, but very drastic and often dangerous. When large dies attain high temperatures, water cooling tends to cause heat checking. Punches and small dies are often successfully cooled with an ample flow of water.

Influence of Die and Tool Lubrication:

1. Heavy graphite bearing greases serve as lubricants and prevent sticking. Usually assures better wear.

Quenching:

Among the data given below are recommendations as to the quenching medium: oil, air and "oil & air". The words "oil & air" signify an interrupted or timed quench. With this method, a tool or die is quenched in oil to a temperature of about 1000° F., or where all color disappears. When this state is reached, the tool or die is removed and allowed to cool naturally in still air until cool enough to be handled in the bare hands. It should then be drawn as directed.

Recommended Compositions, Heat Treatments and Hardnesses

Analysis, %							Heat Treatment (°F.)				
C	Mn	Si	Cr	V	W	Mo	Pre-Heat	High Heat	Quench	Draw	Brinell Hardness
Insert Dies in Upsetters											
0.55	0.25	....	1.25	0.18	2.75	....	1400	1750	Oil	1200	400 to 450
0.30	0.40	1.00	5.00	....	1.30	1.45	1400	1850	Air	1100	400 to 450
0.30	0.30	....	3.25	0.25	9.00	....	1450	2150	Oil & Air	1200	400 to 450
0.25	0.20	....	4.00	0.50	15.00	....	1550	2350	Oil & Air	1200	400 to 450
0.40	0.60	1.50	7.50	....	7.50	....	1550	2100	Oil	1250	400 to 450
Presses, Preloaded Dies											
0.40	0.30	....	1.75	0.18	11.00	....	1550	2150	Air	1100	539 to 578
0.45	0.30	....	2.75	0.40	15.00	....	1550	2200	Air	1150	539 to 578
Gripper Dies for Hand Fed Machines											
0.55	0.25	....	1.25	0.18	2.75	....	1200	1750	Oil	1100	450 to 500
0.55	0.30	0.40	4.00	1.00	....	0.50	1200	1650	Air	800	450 to 500
0.30	0.30	....	3.25	0.25	9.00	....	1200	2150	Air	1150	450 to 500
Gripper Dies for Automatic Machines											
0.30	0.40	1.00	5.00	....	1.30	1.45	1400	1850	Air	1050	444 to 526
0.55	0.35	....	4.00	1.00	....	0.50	1200	1625	Air	1000	444 to 526
Header Dies for Hand Fed Machines											
0.55	0.25	....	1.25	0.18	2.75	....	1200	1800	Oil	1225	430 to 461
0.30	0.30	....	3.25	0.25	9.00	....	1450	2150	Air	1175	430 to 461
0.30	0.40	1.00	5.00	....	1.30	1.45	1400	1850	Air	1100	400 to 450
0.40	0.60	1.50	7.50	....	7.50	....	1550	2100	Oil	1250	400 to 450
Header Dies for Automatic Machines											
0.55	0.25	....	1.25	0.18	2.75	....	1200	1800	Oil	1250	388 to 429
0.30	0.40	1.00	5.00	....	1.30	1.45	1400	1850	Air	1100	400 to 450
0.40	0.60	1.50	7.50	....	7.50	....	1550	2100	Oil	1250	400 to 450
Forging Punches											
0.30	0.30	....	3.25	0.25	9.00	....	1500	2250	Oil & Air	1175	425 to 450
0.30	0.40	1.00	5.00	....	1.30	1.45	1400	1850	Air	1100	400 to 450
0.40	0.60	1.50	7.50	....	7.50	....	1550	2100	Oil	1250	400 to 450

The above data do not represent all of the types being used for the various applications listed, nor do they represent the only heat treatments or hardness values for these types. Neither do the above listings include flat, cut and swaging dies used in beam, steam or air hammers. However, the types and treatments listed represent the broadest general selections being used commercially today in the services noted.

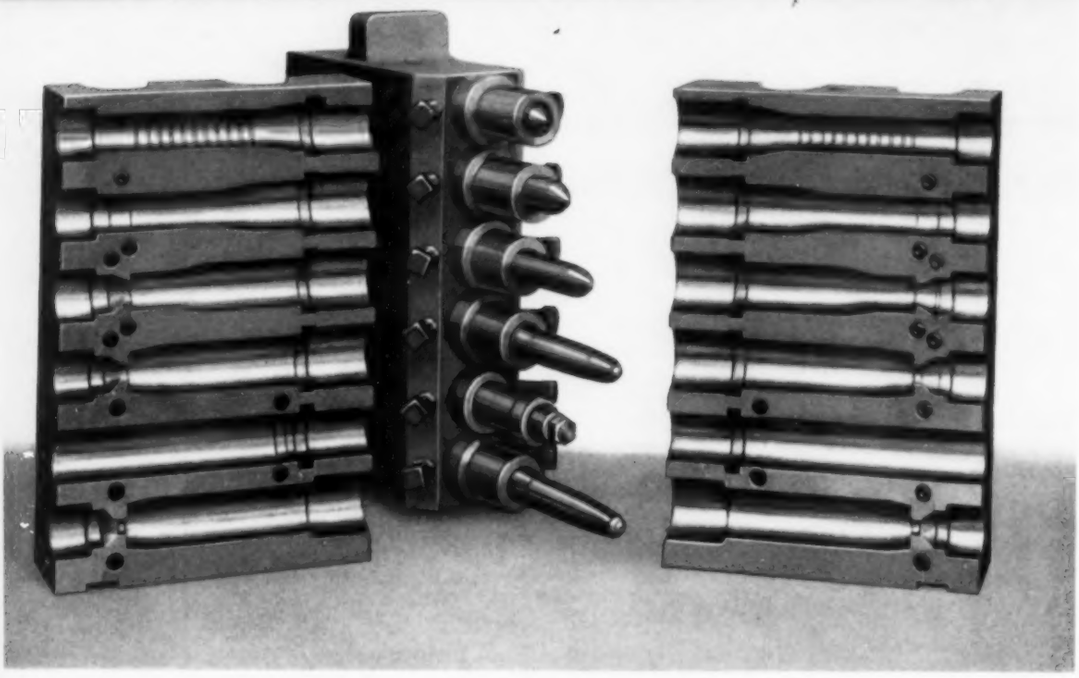


Fig. 2 — Dies (Open) and Piercing Punches for Forging a 75-Mm. Shell in Six Operations in Ajax Forging Machine

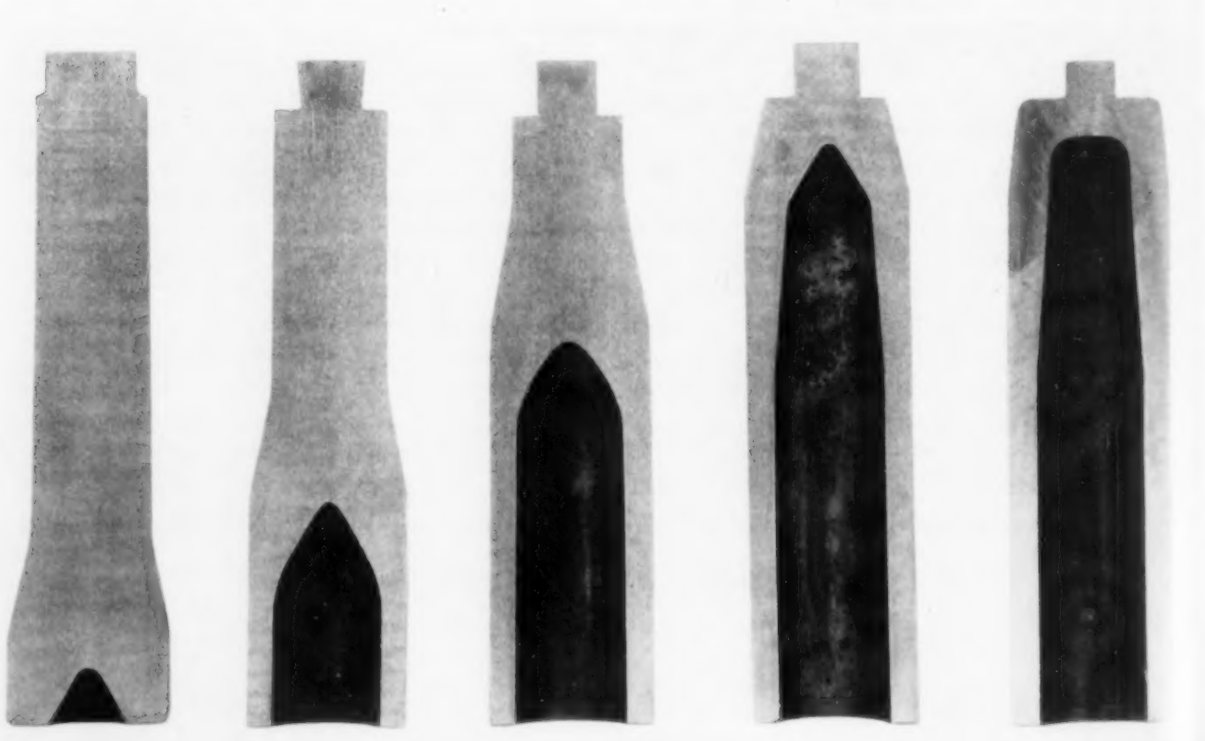
made use of this. The French added a third operation, that of cold drawing the 75-mm. shell forgings to closer dimensional tolerances which considerably reduced the amount of machining necessary to make the finished projectile. Larger caliber forgings, such as the 8 in. and the 9.2 in., were produced by making the cup blanks and then performing the draw operations in large horizontal draw presses called "draw benches".

The passing of the years has seen a vast amount of work directed toward the mass production of forged shell of small and large sizes to advanced metallurgical requirements. Army and Navy ordnance departments have both been unceasing in their efforts to develop plans for future emergencies, and the present conditions have justified their work. The advance in metallurgical experience in the past two decades; the heavier, more rigid and rugged forging equipment having greater adaptability and speed; the years of experience in the use of superior metals and the operation of equipment — all have done much to make the production methods of today far superior to those of yesterday.

Shells Made by the Upsetter Method in the Forging Machine

The forging machine, or upsetter, which was not in the shell picture some 20 years ago, is now well in the foreground for producing complete forgings in sizes up to the 105-mm. shell. This does not indicate that larger sizes *cannot* be produced by the upsetter method, but the capacity of forging machines in sizes over 5 in. is limited, and it has been found desirable to use these large machines for other defense

Fig. 3 — 75-Mm. Shell Forgings (Split on Center Line) as Made in Five Operations in Hill-Acme Machine



needs. Other suitable methods are available for the larger shell forgings.

The upsetter method has been developed to make the 75, 90, and 105-mm. shell forgings and the 60 and 81-mm. trench mortar forgings. They are produced to close tolerances and the powder cavities are held to such size and smoothness that no internal machining is required. The allowance for finishing the outside and ends is very small.

As is doubtless well known, the forging machine basically is a double-acting horizontal press. Heated stock is placed in the machine in a horizontal position and a moving die slides against a stationary die to grip it tight. The piercing or nosing punch is actuated by the crankshaft of the machine; a connecting rod and slide moves the punch against the hot plastic stock, and that portion which is "in the open" is pushed into a cavity in the die. There are a series of working operations called "machine passes" or "steps"; Fig. 2 at above left shows the group of dies and corresponding series of punches or piercers which move or displace metal into a desired position.

Procedure is to place the hot forging stock in the first position, trip the foot lever which starts operations, the machine begins the forging cycle of the first forging pass by sliding the movable die against the stationary die to grip the stock. The cycle continues by the forward motion of the header slide through the rotation of the crank shaft. The punches are fixed in the header slide and the punch in the first pass pushes against the stock not gripped tightly by the dies to move the plastic metal into the die cavity provided for it. The cycle is completed as the header slide recedes and the movable die returns to the open position.

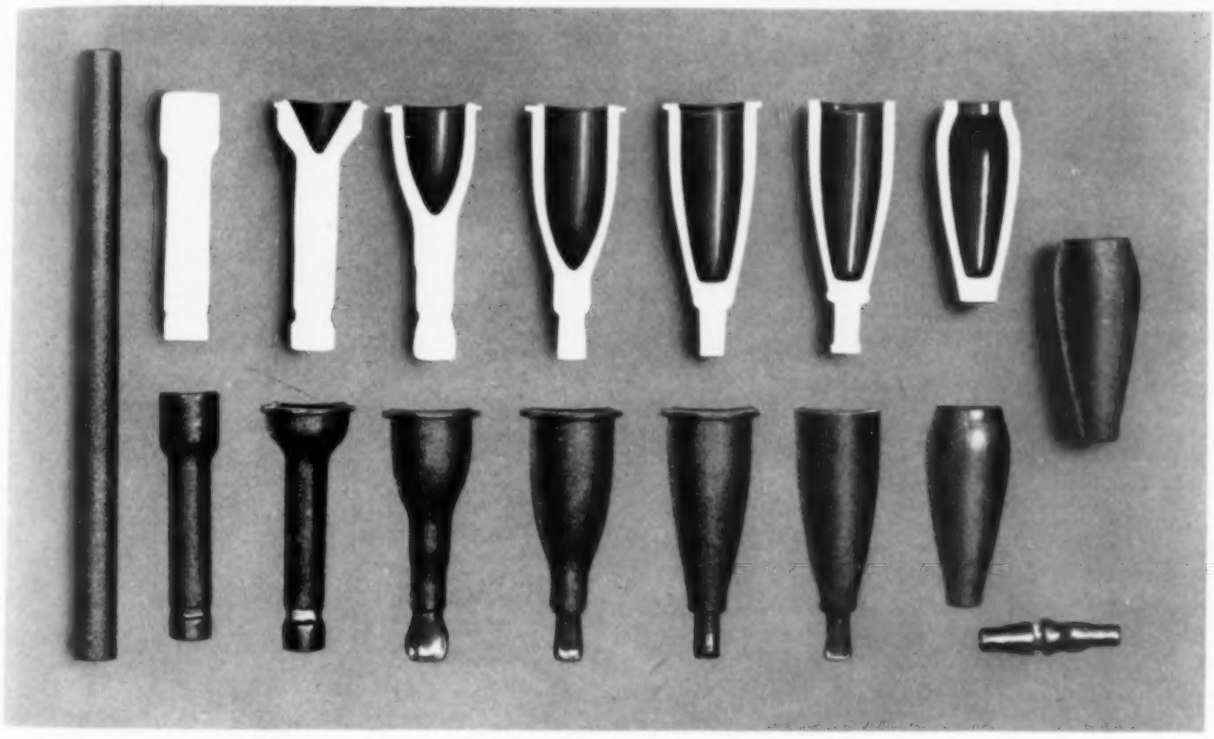


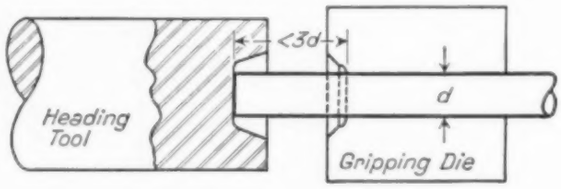
Fig. 4 — Steps in Forging the 81-Mm. Trench Mortar Shell by the Upset Process. (Courtesy Hill-Acme Co.)

The forge man then rotates the stock 90° from its original position and drops it into the second die impression directly below the first. The foot pedal is again tripped and the second forging cycle goes forward. Five working passes or steps are used for the 75-mm. shell forging shown in Fig. 3. For the trench mortar type of nosed forging, six or seven steps are required (Fig. 4). In making the 75-mm. shell forging, the first step upsets a short portion of the stock, and sometimes imparts a centering hole. The second forging step produces about one-third of the necessary cavity, the third forg-

Rules Governing Forging Machine Dies

(Adapted from E. R. Frost; Courtesy National Machinery Co.)

Rule I— The limiting length of unsupported stock that can be gathered or upset in one blow without injurious buckling is three diameters.

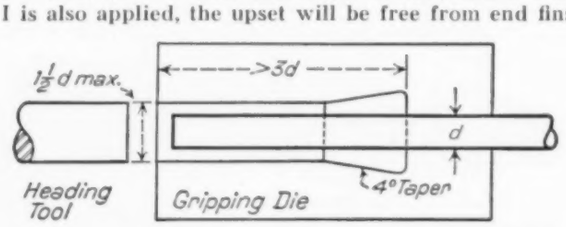


Note (*a*): A safer maximum length is $2\frac{1}{2}d$; little attention need be paid to squareness of end if $l=2d$. If $l>3d$, buckling will occur near the middle of the unsupported length. These principles hold irrespective of whether the stock overhangs the face of the gripping dies, or whether any portion is gathered in either gripping dies, heading tool or both.

Rule II— Lengths of stock more than $3d$ can be gathered or upset in one blow provided the upset is contained in either the gripping die or a straight or slightly tapered hole in the heading tool, and the diameter of the upset made in that blow is not more than $1\frac{1}{2}d$.

Note (*a*): Multiple buckling will be checked by contact with sides of the die, and friction therewith will cause a fin to form around end of upset. Such long upsets cannot be made half in one die and half in the other, for central buckle will receive no side support.

Note (*b*): A safer maximum is $1.3d$, and if Rule I is also applied, the upset will be free from end fins.



Note (*c*): For very long upsets, it is helpful to have the end of the bar at a lower temperature, and to have a minimum diameter upset for the outer half of the die, the inner half tapering 4° to wider diameter at the base.

Note (*d*): In upsetting tubing, wall thickness cannot be increased externally more than 25% at one blow; internal upsets are almost unlimited because arch effect prevents internal buckling.

Rule III— For upsets requiring more than $3d$ in length of stock, and in which the upset is $1\frac{1}{2}d$, the amount of unsupported stock beyond the face of the die must not exceed $1d$ (operation 1, at right).

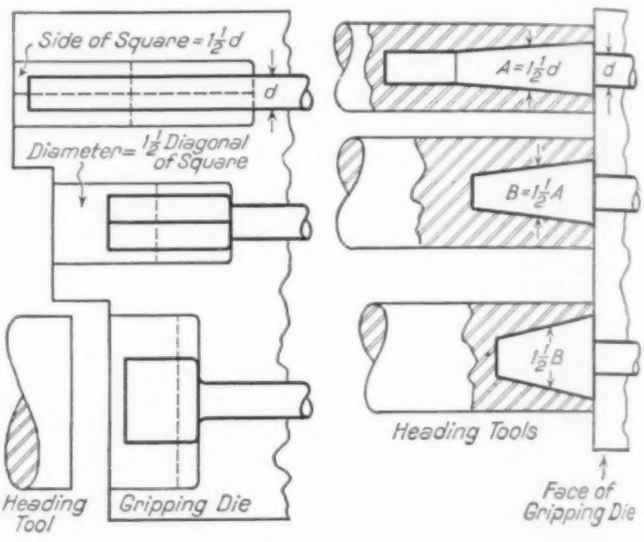
Note (*a*): Unsupported stock can amount to $1\frac{1}{2}\ d$ if diameter of upset is reduced to $1\frac{1}{4}\ d$.

Rule IV— Large amounts of stock can be gathered by multiple application of Rule II and III, and by using square or tapered impressions.

Note (*a*): In making the wide flange in sketch at left, below, the first and second impressions are within the $1\frac{1}{2}\ d$ limit, but the third, being a short upset under Rule I, is unlimited in diameter.

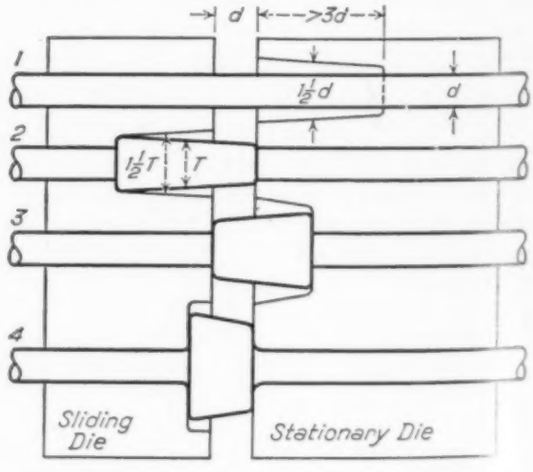
Note (*b*): The side of the square may be $1\frac{1}{2}d$ of the original bar, and the diameter of the next round may be $1\frac{1}{2}$ times the diagonal of the square.

Note (*c*): Tapered holes are proportioned as to their diameters at midlength of unsupported stock.



Rule V— Sliding dies, for upsetting stock at some distance from the end of a bar, are governed by all the above rules.

Note (*a*): Friction along the sides of the sliding die will favor upsetting near its front end, so multiple impressions should be alternately in front and rear half, or alternately in sliding die and gripping die, as shown in sketch below.



ing step increases the cavity to about two-thirds of its final length, the fourth pass obtains about the full length and nearly the full volume, and the final pass forges the full volume and sizes the forging. The trench mortar type of shell forging requires an extra pass for nosing-in.

At this point, it is well to observe the change in forging technique between 1914-1918 and 1941. In any of the early methods, the piercing punch was used to produce the cavity by moving or displacing the metal in a direction *opposite* to that of the travel of the piercing punch. The modern method is to displace the metal by moving it *sidewise* of the punch. It is evident the older method of forcing hot metal to move in a direction against the punch movement required greater power and caused considerably more wear on the dies and tools. Furthermore the grain structure of displaced metal squeezed sidewise is stronger and more uniform than that of the old "extruded" metal (Fig. 3, page 546).

General practice with the forging machine is to provide round bar stock of proper diameter cut in lengths for two shells. While the first end is being forged the second is used for the tong-hold; later when the second end is heated and being forged, the forging is used for the tong hold. Dies are designed to squeeze and neck-down the stock in the center when they close during each forging cycle, and since the stock is turned 90° for each pass, a small connection holds the two completed shell forgings together. This small connection is then easily trimmed off.

Dies and punches become heated under production conditions. The dies are of sufficient size that most of the heat is dissipated without special equipment other than the aid of air cooling. Piercers become quite hot and various means are employed to cool them, the most common method being to use water, either doused on by a helper or sprayed automatically; generally they are also swabbed with a hot-die lubricant.

Hydraulic Presses for Shell Forgings

The same types and sizes of presses which became standard for shell production during the first world war are fundamentally the same presses which serve our needs today, but many improvements have increased production, prolonged die and tool life, and reduced the number of rejects. Hydraulic press speeds have been increased considerably, and the newest machinery incorporates many features unheard of two decades ago. The present technique is to use square billets with rounded corners, convert these billets into the pierced semi-finished shell blank in one press, and finish the shell forgings in a second press. The first operation thus makes use of a piercing press, and the heated forging stock is placed in the lower or stationary die "piercing pot" quite similar to the old method shown at the top of Fig. 1. This piercing pot is fastened to the stationary platen and the piercing punch is fixed to the moving platen. The piercing mandrel moves downward (if the press is a vertical press) to pierce and displace the metal in the center of the billet and force it against the sides of the pot. A "slugging mandrel" may be used, whose function is to force the billet down into a tapered pot to form a conical shell bottom, and to provide a centering hole to guide the piercing punch. If the slugging mandrel is used it is carried on a sliding holder. For long shells the piercing mandrel and pot are moved laterally on the press platen, and this arrangement permits the use of two piercing mandrels, one longer than the other; while one is being used for piercing

Fig. 5 — Round-Cornered Billet Used in Press; First Operation Produces "Pot" (Center), Which Is Immediately, While Hot, Forced Through Drawing Dies to Give Final Form

hot steel, the second is being cooled in an oil bath during the downward stroke of the press. Billet and pot are shown at left and center of Fig. 5, page 549.

An alternate process fixes the piercing pot to the upper moving platen in an inverted position, while the piercing punch is fixed to the stationary platen. This arrangement forces the plastic metal over the stationary piercer during the down stroke and allows the pierced cup to be stripped from the mandrel on the upward stroke of the press. This method incorporates provisions for guiding the mandrel and holding it in center with the pot, to produce concentric shell blanks. Where the hole in the blank or cup is not concentric with the outer diameter, this defect is never corrected in the subsequent drawing operation.

In press forging, the second or drawing operation is performed in the vertical type of press for the smaller diameter shells and in the horizontal presses for the larger sizes. Horizontal drawing presses for long shells are known as draw benches. The original method for drawing shell shown in Fig. 1 was by the use of draw rings where the shell blank was forced through a series of annular rings or drawing dies, and the number of rings in the series depended upon the size of the shell to be drawn.

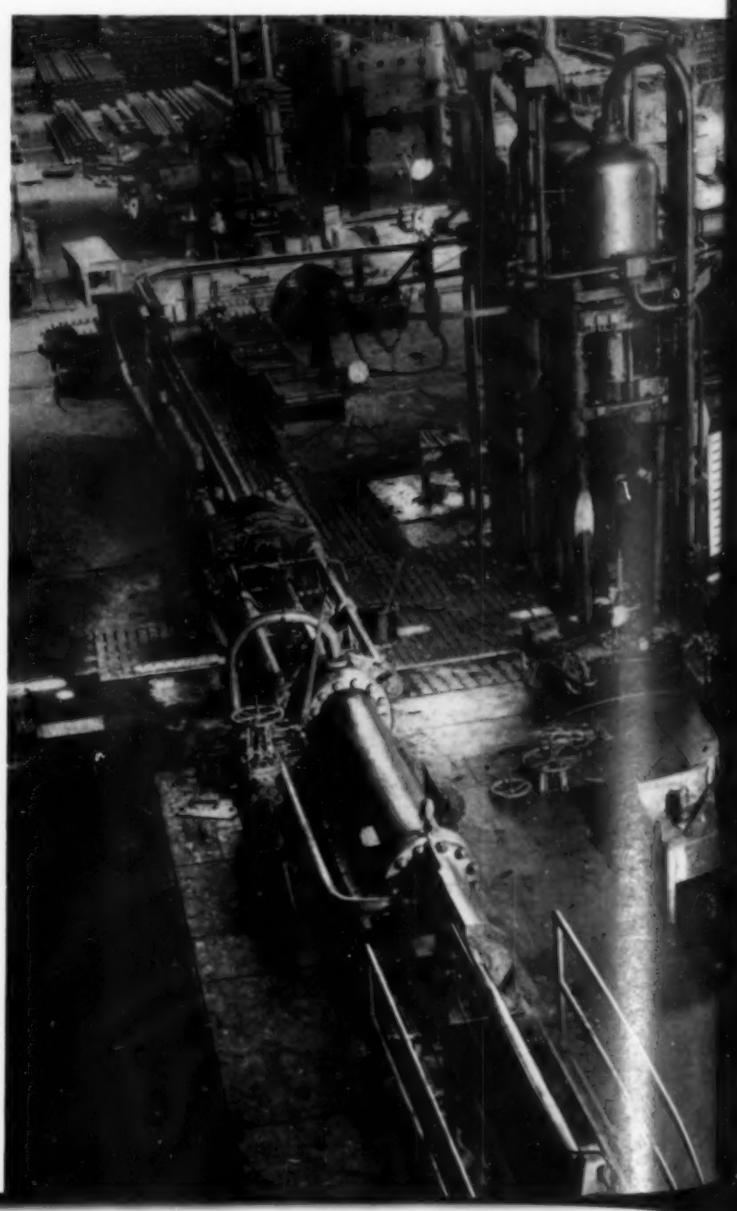
A few years ago a radically different type of drawing die was introduced where the annular ring was replaced by rollers (Fig. 7). Each die head carries three rollers set at 120°, and these rollers are shaped to cover almost the entire outer circumference of the shell. The contact points or positions of the rollers are shifted to a different angle in each succeeding head, so that the hot shell is reduced by principles similar to those used by the steel mill in rolling round bar stock. This roller type of drawing head offers certain advantages in producing a smoother finish and improves the quality of steel macrostructure. Longer die head life and reduced friction (in comparison to the ring type of die) are other advantages. Three heads are required for 3-in. shells; the number ranges up to nine heads for the larger sizes of shell forgings.

Developments in Special Equipment

Interesting other developments in equipment of special design for the rapid production of shell forgings are taking place. A machine known in England as the "Omes Shell Forging Machine" is being introduced in this country. It incorporates both the piercing and drawing operations into one mechanical unit suitable for the smaller sizes of shell forgings, and is based on the operating principle of the conventional forging machine or upsetter. The forging sequence is designed to make use of round cornered square billets.

A heated billet is placed in one of the two open split dies in a horizontal position. The machine cycle is actuated by a foot pedal, and the first working operation is a piercing one wherein the piercing punch is moved forward

Fig. 6 — General View of Shell Forging Shop, Using a Pair of Bald Southwark Piercing Presses (Close Together at Right) Serving a H zontal Hydraulic Draw Bench. The latter has roller type die h



Standard Tolerances for Forgings up to 100 Lb.

Summary of Standards Adopted by Drop Forging Association, 1937

TOLERANCES, within the scope of these standards, shall be either "special" or "regular."

Special tolerances are those particularly noted on the drawings or in the specifications, and apply only to the particular dimension or thing noted. They may state any or all tolerances in any way as occasion may require. Regular tolerances apply in all other cases.

Regular tolerances in general forging practice are known as (*a*) "commercial standard," for general forging practice, or (*b*) if extra close work is desired involving additional expense and care in the production of forgings, "close standard" may be specified.

Class I—Thickness Tolerances

For drop hammer forgings, thickness tolerances shall apply to the overall thickness measured in a direction perpendicular to the fundamental parting plane of the dies.

For upset forgings, thickness tolerances shall apply to the metal actually enclosed and formed by the dies, measured parallel to the direction of travel of the ram.

Thickness Tolerances in Inches

Max. Net Weight	Commercial		Close	
	Minus	Plus	Minus	Plus
0.2	0.008	0.024	0.004	0.012
0.4	0.009	0.027	0.005	0.015
0.6	0.010	0.030	0.005	0.015
0.8	0.011	0.033	0.006	0.018
1	0.012	0.036	0.006	0.018
2	0.015	0.045	0.008	0.024
3	0.017	0.051	0.009	0.027
4	0.018	0.054	0.009	0.027
5	0.019	0.057	0.010	0.030
10	0.022	0.066	0.011	0.033
20	0.026	0.078	0.013	0.039
30	0.030	0.090	0.015	0.045
40	0.034	0.102	0.017	0.051
50	0.038	0.114	0.019	0.057
60	0.042	0.126	0.021	0.063
70	0.046	0.138	0.023	0.069
80	0.050	0.150	0.025	0.075
90	0.054	0.162	0.027	0.081
100	0.058	0.174	0.029	0.087

Class II—Width and Length Tolerances

Width and length tolerances shall be alike, and are classified in three subdivisions (*a*) shrinkage and die wear tolerance, (*b*) mismatching tolerance, (*c*) trimmed size tolerance.

For drop hammer forgings, width and length tolerances shall apply to the metal actually enclosed and formed by the die, as measured parallel to the fundamental parting plane of the dies.

For upset forgings, width and length tolerances shall apply to directions perpendicular to the direction of travel of the ram.

II(a)—Shrinkage and Die Wear Tolerances

See table below. These shall not be applied separately, but only as the sum of the two; they shall be measured in such a way as to eliminate draft or variation in draft. They apply to that part of the forging formed by a single die block, and to no dimension crossing the parting plane.

Shrinkage and Die Wear in Inches

Length or Width	Shrinkage			Die Wear	
	Commercial + or −	Close + or −	Max. Net Weight	Commercial + or −	Close + or −
1 in.	0.003	0.002	1 lb.	0.032	0.016
2 in.	0.006	0.003	3 lb.	0.035	0.018
3 in.	0.009	0.005	5 lb.	0.038	0.019
4 in.	0.012	0.006	7 lb.	0.041	0.021
5 in.	0.015	0.008	9 lb.	0.044	0.022
6 in.	0.018	0.009	11 lb.	0.047	0.024
For each additional inch add	0.003	0.0015	For each additional 2 lb. add	0.003	0.0015
For example:			For example:		
7 in.	0.021	0.011	13 lb.	0.050	0.026
12 in.	0.036	0.018	21 lb.	0.062	0.031
18 in.	0.054	0.027	31 lb.	0.077	0.039
24 in.	0.072	0.036	41 lb.	0.092	0.046
36 in.	0.108	0.054	51 lb.	0.107	0.054
48 in.	0.144	0.072	71 lb.	0.137	0.069
60 in.	0.180	0.090	91 lb.	0.167	0.084

II(b)—Mismatching Tolerance

Mismatching is the displacement of a point in that part of a forging formed by one die block of a pair, from its desired position when located from the part of the forging formed in the other die block of the pair, measured in a projection parallel to the fundamental parting plane of the dies. It does not include any displacement caused by variation in thickness of the forging; mismatching tolerances are independent of and in addition to any others.

Mismatching Tolerance in Inches

Max. Net Weight	Commercial	Close
1 lb.	0.015	0.010
7 lb.	0.018	0.012
13 lb.	0.021	0.014
19 lb.	0.024	0.016
For additional 6 lb. add	0.003	0.002
For example:		
37 lb.	0.033	0.022
55 lb.	0.042	0.028
79 lb.	0.054	0.036
97 lb.	0.063	0.042

II(c)—Trimmed Size Tolerances

The trimmed size shall not be greater nor less than the limiting sizes at the parting plane imposed by the sum of the draft angle tolerances and the shrinkage and die wear tolerances.

Class III—Draft Angle Tolerances in Degrees

	Drop Forgings		Upset Forgings	
	Outside	Inside Holes	Outside	Inside Holes
Nominal angle	7	7 or 10	3	5
Commercial limits	0 to 10	0 to 13	0 to 5	0 to 8
Close limits	0 to 8	0 to 8	0 to 4	0 to 7

Class IV—Quantity Tolerances

Any quantity shipped within the quoted limits of over-run or under-run shall be considered as completing each release or part shipment of an order. Limits are as follows:

Quantity Tolerances

Number on Order	Over-run	Under-run
1 to 2	1 piece	0
3 to 5	2 pieces	1 piece
6 to 19	3 pieces	1 piece
20 to 29	4 pieces	2 pieces
30 to 39	5 pieces	2 pieces
40 to 49	6 pieces	3 pieces
50 to 59	7 pieces	3 pieces
60 to 69	8 pieces	4 pieces
70 to 79	9 pieces	4 pieces
80 to 99	10 pieces	5 pieces
100 to 199	10%	5.0%
200 to 299	9%	4.5%
300 to 599	8%	4.0%
600 to 1,249	7%	3.5%
1,250 to 2,999	6%	3.0%
3,000 to 9,999	5%	2.5%
10,000 to 39,999	4%	2.0%
40,000 to 299,999	3%	1.5%
300,000+	2%	1.0%

Class V—Fillet and Corner Tolerances

Fillet and corner tolerances apply to all intersecting surfaces even though drawings or models indicate sharp corners. If such drawings or models have or indicate (even though actual dimensions are not specified) fillet or corner dimensions of larger radii than the following standards, such larger dimensions shall be considered as actually specified and the tolerances shall be "special tolerances."

Where a corner tolerance applies on the meeting of two drafted surfaces, the tolerance shall apply to the narrow end of such meeting and the radius will increase toward the wide end. The total increase in the radius will equal the length of the drafted surface in inches, multiplied by the tangent of the nominal draft angle.

Fillet and Corner Tolerances

Max. Net Weight	Commercial	Close
0.3 lb.	3/32	3/64
1 lb.	1/8	1/16
3 lb.	5/32	5/64
10 lb.	3/16	3/32
30 lb.	7/32	7/64
100 lb.	1/4	1/8

Fig. 7 — Roller Type Die Head for Horizontal Hydraulic Draw Bench. One or two sets of such rolls will size a forging; four or five are necessary to draw down wall thickness

(as in the conventional upsetter) and enters through a steel guide bushing to pierce and expand the billet with the metal moving toward the walls of the die. As the punch recedes the pierced blank is stripped, falls clear and is automatically placed in the second working operation, which is the conventional draw bench part of the machine.

The machine has double tooling so that one set of tools can be cooled while the other set is working. Three drawing rings of the roller type are used for the draw. The Omes shell forging machine produces forgings of uniform wall thickness so that no machining is required on the inside of the cavity.

Another recent development of interest in the production of the small and medium sized shell forgings is the use of cross rolls, driven in a manner similar to the cross rolls or "reels" used in tube mills. In this device a pierced blank or cup — produced either in the conventional piercing press or in the drop hammer — is conveyed to a loading station of the finishing mill, where it enters the breakdown pass of the humped rolls with a smoothly machined mandrel inserted in the cavity of the pierced blank. The mandrel is kept bottomed in the blank by pressure from a push-cavity in the forging end. After leaving the rolls, the forging is sized through a set of triple rollers with mandrel still inserted, and then the mandrel is automatically stripped, leaving the shell forging completed and ready for machining. This so-called Witter process was first used on an Assel mill at Timken Steel & Tube Co., and is now promoted by Salem Engineering Co.

An announcement just made describes a four-stage shell forging machine completely continuous in operation, designed to eliminate all manual handling from the time the hot billet is placed in the de-scaler until the finished drawn forging is delivered by the cooling conveyor. This huge "Clearing" machine is designed along the basic principles of the forging and upsetting machine; the dies are mounted on a vertical-faced turret and index the work around to successive operations. The mechanism is designed to work on three forgings at once.

The three essential piercing stages are accomplished along lines similar to the conventional upsetter, the first operation upsetting the

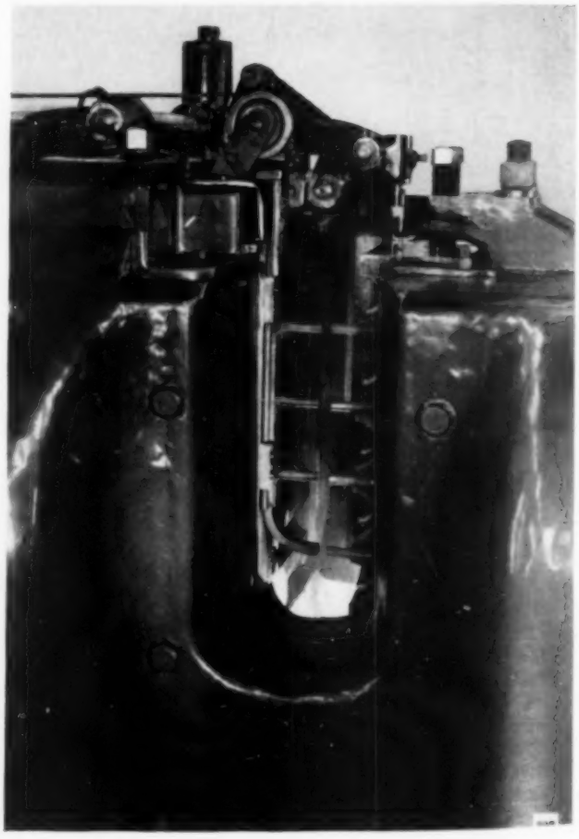


Fig. 8 — Stock Manipulator in Throat of a Hill-Acme Forging Machine. Fingers at left ride the stock down one position at a time

billet slightly and piercing it slightly. The second and third stages continue and complete the piercing operations and the fourth stage draws the shell through triple rollers. Between working stages, the die table has three cooling stages. Piercing punches are cooled by hot water and sprayed with a colloidal graphite lubricant. Punches in this machine are self aligning and adequate automatic hydraulic stripping devices are used.

More conventional methods of relieving the forgeman of some of the heavy labor is the simple "ladder" shown in Fig. 8. Alternate operation of the fingers on this stock manipulator, in step with the opening of the dies, rides the billet from die to die downward to the finish.

Fig. 9 — Ajax-Hultgren Salt Bath, Heating 155-Mm. Shell for Nosing

Heating the Forging Stock

Heating the billets is a vitally important factor in the production of shell forgings. The metallurgical structure and strength of the projectile is dependent upon proper heating of the stock; overheating will cause excessive scaling and poor grain structure; uneven heating will tend to force the piercing punches towards one side or the other and throw the cavity out of concentricity with the outside diameter of the shell. (As mentioned before, this latter condition cannot be remedied in drawing operations.) The furnaces used during the first world war period were mostly of the box or batch type, fired by oil. Towards the end of the war rotary heating furnaces were being tried. In the past decade the importance of good forge heating has become universally recognized and furnace engineers have gone a long way in developing better equipment.

Nowadays the furnaces are mainly fired with fuel oil or gas; electric heating has been tried in a few shops. In the oil or gas fired furnaces, the available types are the batch furnace (vastly improved over its predecessor of 20 years ago), the rotary heating furnace, and the straight line continuous furnace with pusher.

The batch furnace of today is highly satisfactory for general shop work where a variety of sizes and lengths of bars and billets must be heated. It can also be used satisfactorily for heating stock for shell forgings but this type of furnace requires a greater degree of skill from the heater to produce good work than does the continuous furnace, and where long production runs on shell forgings are required, the continuous furnace is generally preferred.

Of the two continuous types, the rotary forge heating furnace has taken the preference, probably because the rotating hearth works equally well on round or square stock, whereas the pusher type of straight-line furnace is primarily designed for square stock. The rotary furnace (such as the one illustrated in Fig. 10) has a single door for charging and discharging. The usual procedure is to take out a piece of hot stock and replace it with a cold piece. The heating cycle can be set to obtain the desired temperature in a given time period so that the stock is thoroughly heated to obtain that "soft" heat resulting in the best plastic condition of the metal.

The usual temperature for shell forging is from 2200° F. to 2300° F., and at this temperature some scaling is sure to be encountered. With proper furnace design, the amount of scale can be reduced to a very thin layer which is easily removed by a scale breaker or by water under pressure. Scale is detrimental to dies and tools and can even pit the forgings. Some men in the industry believe that this point is not of importance; if the furnace causes scaling, just let the stock scale, and remove it in the scale breaker. It would seem, however, that where excessive scaling occurs, the furnace conditions must be oxidizing, and oxidizing conditions are detrimental to the structure of the steel, causing surface overheating and possible "burning". At any rate, scale means a loss of good metal. Good furnace design can eliminate most of the scale and obtain a fairly neutral furnace atmos-

phere, and such good conditions surely add to the life of the furnace refractories. The importance of uniform heating has also been mentioned in producing concentric cavities — an important fact when inner diameters are not machined and machining allowances on outside diameters are small.

Electric heating is being given a thorough trial. It can be applied in one of two ways, either by coreless induction heating or by the electrically heated salt bath. The first method is being used on shell forgings up to the 105-mm. size. It is very satisfactory, in that the heating is so fast that the billet is free from scale; likewise there is no surplus heat and the furnace operator is much more comfortable. All that is necessary is to provide a sufficient number of heaters for continuous supply of hot metal to the forging machine.

Figure 9 shows one of a battery of Ajax-Hultgren electric salt bath furnaces at Willys-Overland (Toledo), heating machined, high explosive 155-mm. shells for nosing. A temperature some 500° lower than forging is sufficient, and avoids eccentricity and wrinkling. Only 9 in. of the end is heated, and a sharp line of demarcation is noted; speed is rapid (40 an hour) and a salt film prevents oxidation.

Production Possibilities

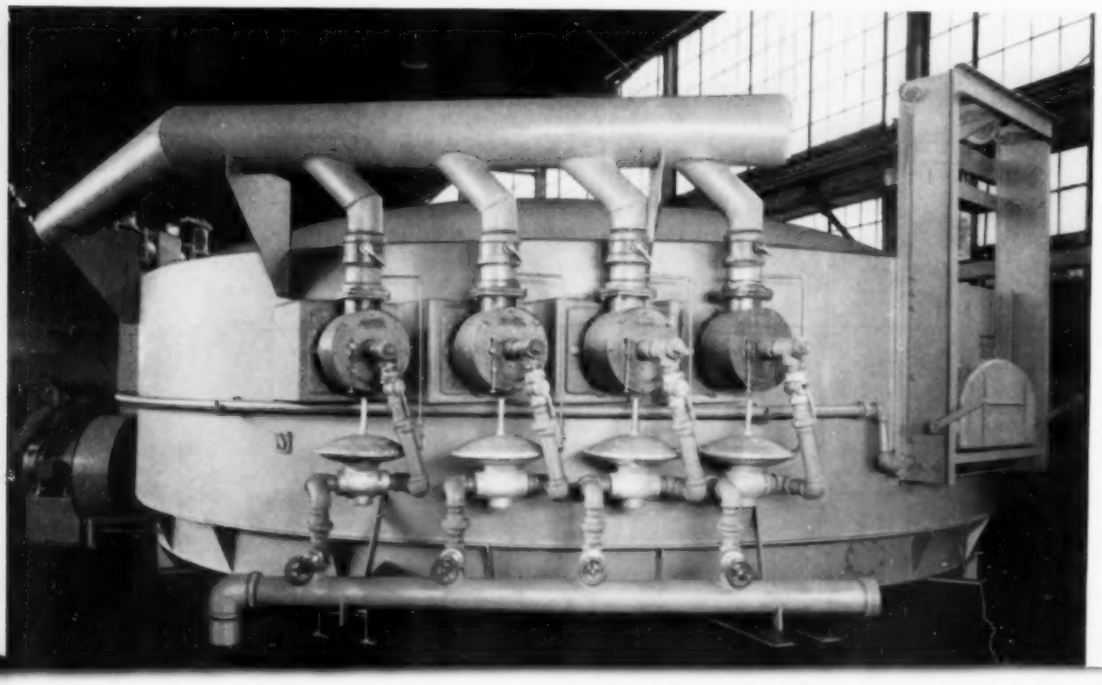
The logical question now arises as to the production possibilities of the various methods. It is difficult indeed to make a fair comparison, because figures for hourly production are the only comparable data readily available, and these do not offer any better criterion than claimed "miles per gallon" for several makes of cars. The factors of continuous production, day in and day out for long periods, frequency of machine breakdown, availability of required bar or billet stock, type of heating available, size of operating crew, type of help necessary, quality of the finished shell forging, life of dies and tools, percentage of rejected forgings, necessity to saw ends off, number of machines in the forging cycle, cost of repairs — all these factors are important in making any just comparison. Some of the methods are tried and known, while others are so new that the data must be considered as "claims" until authentic figures are developed.

In the first world war period, production on the smaller sized shell forgings, such as sizes in the 75 to 105-mm. shells, started at about 200 to 250 forgings in an eight hour day and towards the end of the war period this had been stepped up to over 500. Present production possibilities are considerably higher. The forging machine or upsetter has demonstrated abilities to produce from 600 to 1000 shell forgings of 75-mm. and even 105-mm. caliber in an eight hour shift. Hydraulic piercing and drawing presses are of proven and tried merit, and their present production has increased substantially over their previous war records, with the daily output of shell forgings depending upon the size of shell being forged. For 75-mm. and 105-mm., the hydraulic piercing and drawing presses produce 1300 to 2000 shell forgings in eight hours.

The Baldwin-Omes shell forging machine offers possibilities of 1200 pieces in eight hours and the machines composing the cross rolling process indicate over 2000 forged shells in the eight hour period. The Clearing Automatic Shell Forging Machine has claimed nearly 2000 shells of 90-mm. size in eight hours.

The real conclusion to be drawn is not a comparison of records or claims of the various machines, methods, or techniques. The more satisfactory conclusion arises from the circumstance that American ingenuity, through its engineers, metallurgists, technicians, managers, and tied together by industry and labor, has the ability and the equipment to produce shell forgings in whatever quantities that may be required.

Fig. 10 — Rotary Hearth Heating Furnace. (Lee Wilson Engineering Corp.)



An obvious division of the furnace field is between electric furnaces and gas fired. While electrically heated resistors are widely used for heat sources, recent years have witnessed many more direct means of transmitting heat to the part, or even the generation of heat within the piece itself

Industrial Electric Heat

ELECTRIC HEAT for industrial purposes received its first real acceptance in the United States during the first World War, but did not become widespread until the industrial expansion that occurred from 1920 to 1930. The rapid expansion of electric heat during this ten-year period was due to two things. First, the development and appreciation of the valuable properties which could be obtained by the careful heat treatment of alloy steels. Second, the fuel-fired equipment that was formerly used was often crudely built and was little more than a pile of bricks held together by angle irons and fired by the simplest kind of burners. Automatic temperature control was first being used in mass production in the early 1920's.

Electrically heated furnaces, well insulated to conserve the more expensively generated heat units, and well engineered, could turn out better work at a lower overall cost per pound than the fuel-fired furnaces. The ready acceptance of electric furnaces was assured. In some cases during those early days the first electric furnace to go into a plant showed such great savings over the older equipment that everything was electrified without proper consideration being given to all conditions. This occasional over-selling added much to the later confusion.

Manufacturers of fuel-fired furnaces had to meet this competition and began to improve their units and really engineer them for the job at hand. Users of heat treating equipment had not yet employed competent furnace engineers, and the management was frequently so confused by the arguments of both sides that they hardly knew what to buy. The slackening of the industrial pace during the early thirties and a better knowledge of furnaces by the user gave time for a better analysis and a firmer basis for the installation of the proper equipment. It is therefore the more gratifying to report that today the use of electric industrial heat is still increasing, and it is firmly entrenched because it is being used where it can show worth while savings to the purchaser.

Heat Sources

It is loose talk for one to say that any one kind of heat source is the best and most economical for every purpose. Each job should be carefully studied to get the best furnace for each application. The actual cost of heat treating an article is usually a small part of the total cost of manufacturing that article, so a more expensive but more readily controlled or readily accessible piece of equipment may be justified if the final cost of the finished article can be reduced. A few pieces of electrically heated equipment properly located may be the answer. In other cases large blocks of electric furnaces can be justified because the load diversity makes the fuel cost for bulk heating competitive with hydrocarbon fuels.

By Glenn Coley
Metallurgist, The Detroit Edison Co.

For many years about the only type of electric heat for heat treating was supplied through metallic resistors of the familiar nickel-chromium type. Today this material still predominates due to its steady improvement by the careful work and research of its manufacturers. This material will stand continuous operation in air at 1850° F. and in a properly designed and operated furnace will last for years. Other metallic resistors, mostly of the iron-chromium-aluminum type, are used for temperatures up to 2400° F., but their acceptance has not been universal because special supports are required to hold them in place at operating temperatures.

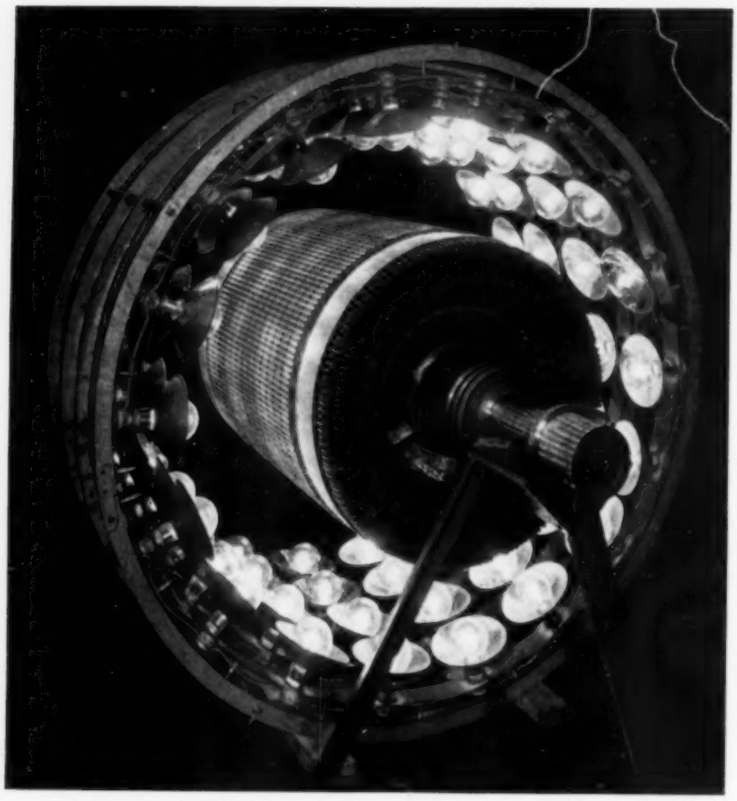


Fig. 1 — Drying Insulating Varnish on Armatures Under Infra-Red "Light". (Courtesy Ford Motor Co.) Banks of lamps with gold reflectors are widely used to bake synthetic resin enamels rapidly on automobile finishes

Non-metallic resistors of the silicon carbide type have long been used for high speed steel hardening furnaces and for some forge heating and ceramic furnaces.

Devices have recently been perfected that operate in connection with the pyrometer control to limit the electric input to the furnace. As the furnace approaches the operating temperature the current flow is regulated so it is fed in gradually reducing steps. In this way the temperature approaches its maximum gradually and prevents "over-shooting" after the pyrometer has shut off the power.

It may be news to some that the widest and most diversified use of electric heat in industry is in the small units represented by immersion heaters, strip heaters, and cartridge heaters. These units have been improved until they are now commonly used for long periods at operating temperatures up to 1500° F. Their ease of control and installation and their low cost frequently enable the plant maintenance crew to build the complete heating device. They have hundreds of applications, most of which are apparent to the prospective user, and include the heating of oil baths, cleaning solutions, tanks, electroplating tanks, white metal baths. With special sheaths they can be used for many chemical processes. They are also used for air heating in crane cabs, watchman houses, isolated offices, airplane testing, oil pipe lines, pump houses, drying ovens, and so on indefinitely. Cartridge units can be inserted in small areas where local heating is desired such as dies for plastic presses, die casting machine dies, nozzles, and similar applications.

A recent development is in the use of near infra-red radiation, particularly for drying and baking of lacquers, varnishes and enamels. For this class of work banks of incandescent lamps in reflectors offer the possibility of greater speed of heating, lower cost for equipment and installation, adaptability to special jobs, and elimination of warm-up period. Drying lamps for radiant heating are dependable and can be put where you want them. A range of temperatures from 300 to 600° F. is readily attainable, if the object to be heated is such as to allow the necessary concentration of radiant energy and heat absorption. Pieces which present a relatively large area to the lamps in proportion to their mass offer the most promising field for application. Typical objects of this type are metal cabinets, automobile bodies and similar pieces with large surface. While

infra-red is usually considered a means for drying a surface or thin film, some interesting work has been done on the drying of foundry molds, pointing to a considerable time saving in completely drying heavy sand molds.

Atmosphere Furnaces

Carburizing by means of gaseous atmospheres instead of packing in solid compound is not new, but some of the more recent equipment for using this old art is new. Vertical, cylindrical gas carburizing furnaces have been recently perfected and widely accepted by the industry. These furnaces, being electrically heated, have easy and accurate temperature control, highly uniform carburizing, short cycles and adaptability to various sizes of work. The gas may be made from an oil that is vaporized upon its introduction into the furnace, or from cylinder gas of uniform composition. Uniformity of carburizing is assured by a fan within the furnace that gives positive circulation of atmosphere throughout the charge. The work, which is loaded into baskets, is introduced through the top of the furnace and can be either slow cooled or quenched directly from the carburizing temperature. The ease with which the size and shape of the work can be changed from charge to charge and the variety of cooling methods available make this unit one of the most adaptable and useful.

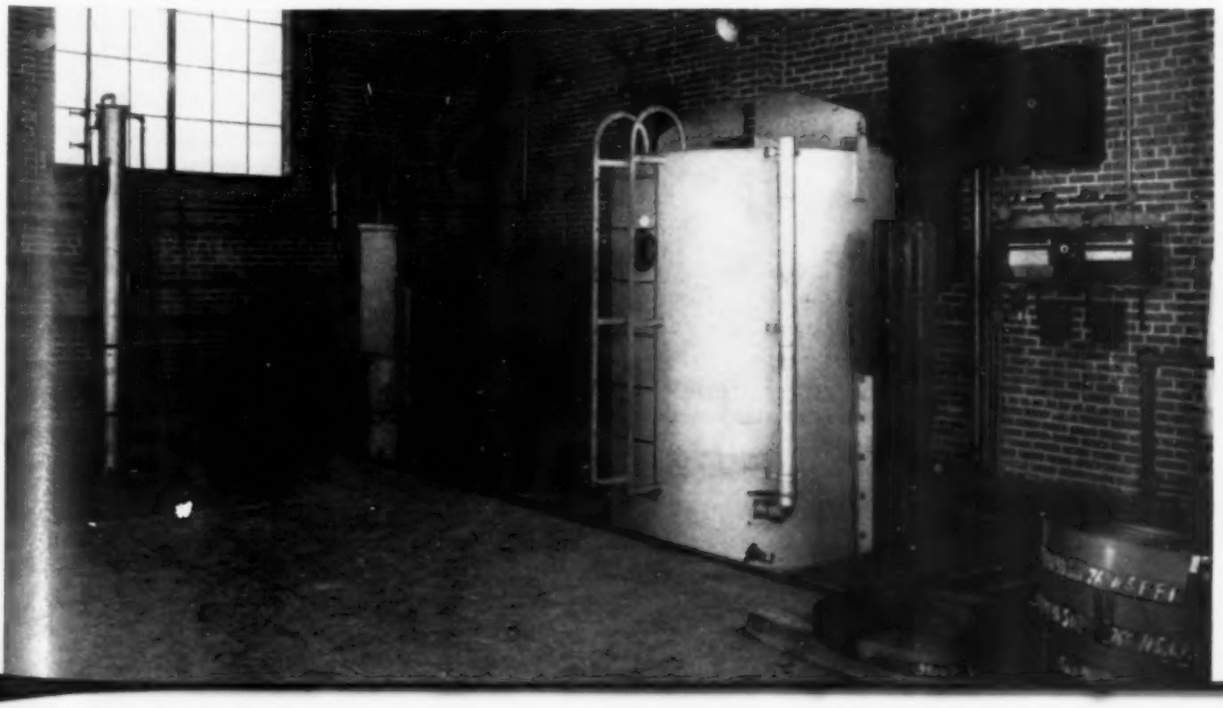
Controlled atmospheres, which are so widely accepted today, are not contingent upon the use of electric heat but are frequently more easily controlled and used in electric furnaces because they can be introduced directly into the heating chamber without fear of contamination from combustion products. Tool hardening furnaces have taken the lead in this field. All types of toolsteel are accurately hardened without scale or decarburization. Accurately formed cutting tools with thin, sharp edges can be completely hardened without subsequent grinding or lapping. Silicon carbide resistor furnaces are used for this purpose and the elements show a good life even when operating at 2350 to 2400° F. The newer resistors can be used without water cooled terminals, which simplifies the installation and eliminates the heat losses to the cooling water.

There is no single atmosphere that will serve all hardening purposes, but starting with the experience and recommendations of the furnace builders the correct atmosphere can be found for practically any job after some experimenting by the user. The increased tool life brought about by proper hardening can go a long way toward relieving a shortage of tools due to increased production.

Copper Brazing

A special but important case of atmospheric control is for copper brazing. This is the process where steel assemblies are made (by pressed fits or tack welding) with pieces of copper wire or copper powder placed near the joints. When this is heated to approximately 2100° F. in a reducing atmosphere the copper flows between the closely fitting sections to make a strong joint. This process has simplified many complicated operations, and by re-designing has permitted entirely new assemblies to be made.

Fig. 2. — Electrically Heated Cover (Westinghouse) for Bright Annealing High Carbon Steel Strip in High Nitrogen Gas, Prepared From Burned City Gas by Special Liquids for Absorbing the CO_2 and H_2O



If the parts are clean when introduced into the furnace no flux is needed and the work comes out clean and bright.

Silver solder or low melting brazing wire can be substituted for copper on non-ferrous materials that would melt at 2100° F.

Salt Baths

Heating steel in baths of molten salt has been used for many years. Every heat treating department no matter how small has one or more externally heated cyanide pots for hardening small, miscellaneous parts.

Most salts when cold are poor conductors of electricity but when molten conduct current to varying degrees. The principle of heating salt baths by the resistance to electric currents passing through them has been in limited use for a long time. The last few years have seen a rapid change in the salts available and a more careful study of the electrical problems involved has made these furnaces available for a wide variety of heating jobs.

The salts are used in metallic or refractory pots with insulation packed closely around the outside of the pot. Electrodes, in the form of metallic bars, are immersed in the salt; their shape and spacing varies with the make of furnace. Electricity is fed to the electrodes through a low voltage transformer with several variable voltage taps available to regulate the heat input. Due to a combination of magnetic currents and heat differential at the electrode surfaces there is a rapid circulation of the molten salt that gives a uniform temperature throughout the bath.

By a proper arrangement of sets of electrodes these furnaces can be made any length, and since the pots have insulation packed against the bottom and sides, troublesome problems of support are avoided. The heat being generated inside the pot makes them operate at a temperature no higher than the bath, in contrast to a pot hotter than the bath when the heat must be transferred from an outside source through the pot walls. Pots of welded boiler plate can be employed for temperatures up to 1600° F. because they are protected by the salt and insulation against oxidation. Temperatures higher than 1600° F. require alloy or refractory pots for long life.

Baths are started from cold in one of several ways. A resistance wire may be buried in the salt between the two electrodes, granular carbon may be placed between the electrodes to act as a conductor, or a molten path may be made between the electrodes by a blow torch. Once a path of molten salt is established between the electrodes, melting continues until the entire bath is liquid.

Work to be heated is immersed into the salt either after loading in baskets or placing on special racks. The salt may be the conventional sodium cyanide (which gives a hard shallow case), one of the activated salts that will give any depth of case dependent upon the time in the bath and the temperature, or a neutral salt suitable for bright hardening. Work that is accurately ground can be heated in a carburizing bath for the proper depth of case, then transferred to a neutral salt bath at the proper hardening temperature and held until equilibrium is reached, after which it is quenched in oil or water. The

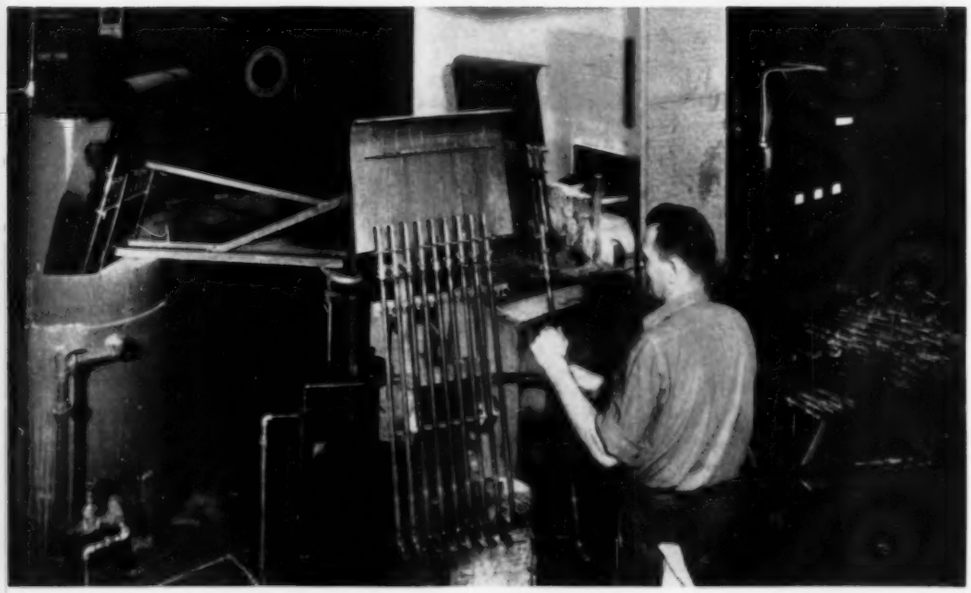


Fig. 3 — Brazing Gear Shift Lever Assemblies, and Simultaneously Heating for Hardening, at Studebaker Corp. (Courtesy Bellis Heat Treating Co.) Assembly has already been brazed at one end; workman is filling a rack, which will be dipped into the electrically heated salt bath at rear, and later be quenched in tank at extreme left

film of molten salt protects the work from scaling while moving from one bath to another.

The composition of the case produced in an activated bath differs from that after the conventional carburizing in hydrocarbon or solid compound. The active element in the bath is sodium cyanide which is oxidized by air to sodium cyanate, NaCNO. This decomposes to give CO and nascent nitrogen. The CO gives up its carbon to the steel to form Fe_3C, as in regular carburizing, while the nitrogen forms iron nitride. The hardness of the case is due to the combined action of iron carbide and nitride.

Fig. 4 — Ajax-Hultgren Unit in Kelsey-Hayes Wheel Co. Plant, Hardening Cylinder Sleeves for Allison Engines. Neutral salt bath operates at 1550° F. (Courtesy Ajax Electric Co.)

Salt baths offer an ideal method for neutral hardening and are widely used in industry. One of the first applications was for hardening high speed steel. Stable salts are now available that will stand temperatures of 2200 to 2400° F. without pitting or scaling the work, and will not produce a soft skin. Salts are also available that permit neutral hardening at temperatures from 1500 to 1800° F. This opens a field for carbon and alloy steel parts such as gears where the parts can be finish machined and ground before hardening.

Electrically heated salt bath furnaces are finding wide application in treating aluminum and magnesium parts. Some of these alloys are subject to serious grain growth when held at temperatures below their hardening temperatures, but are not so affected at the correct hardening temperature if heated fast enough through the dangerous range. The salt bath heats rapidly because the work is completely surrounded by and in direct contact with a heating medium of high heat conductivity. The salt layer drag-out also prevents contact with air while transferring the work.

Salt bath furnaces are also being used for brazing. The assembly to be brazed is made in the usual manner, and the part then immersed in molten salt held slightly above the melting point of the brazing compound. The part may then be quenched in water or air cooled depending on the properties required. If air cooled, the salt film protects the part from oxidation. It is sometimes possible to combine brazing with surface hardening in the same bath.

Salt baths also offer excellent means for localized heat treatment by immersing only that part to be heated. Heating billets for forging offers attractive possibilities and is being used to some extent. This application should be particularly useful in end heating because the heating line can be sharply defined. The possibilities have not been fully developed but seem to offer definite advantages.

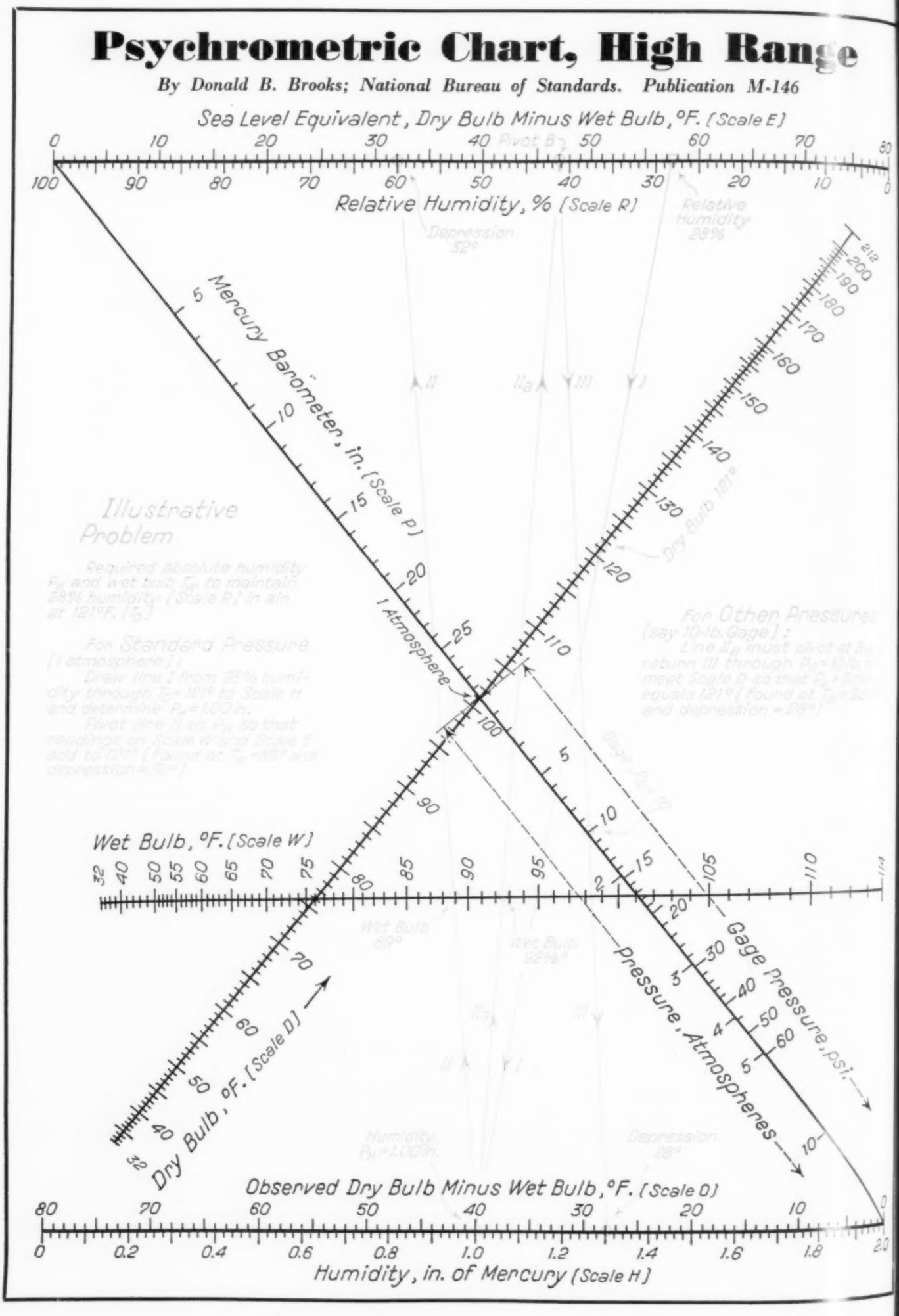
Induction and Resistance Heating

When electricity is passed through a conductor, resistance to the passage of the current causes the conductor to become heated. The amount of heat generated is directly proportional to the resistance. This property is used commercially in spot, seam and other resistance welding. It is also used for heat treating and forge heating by placing the steel object between two electrodes, usually copper, and passing the electricity through the steel object which, having a higher resistance that the copper electrodes, heats uniformly and rapidly.

(Text continues on page 572)

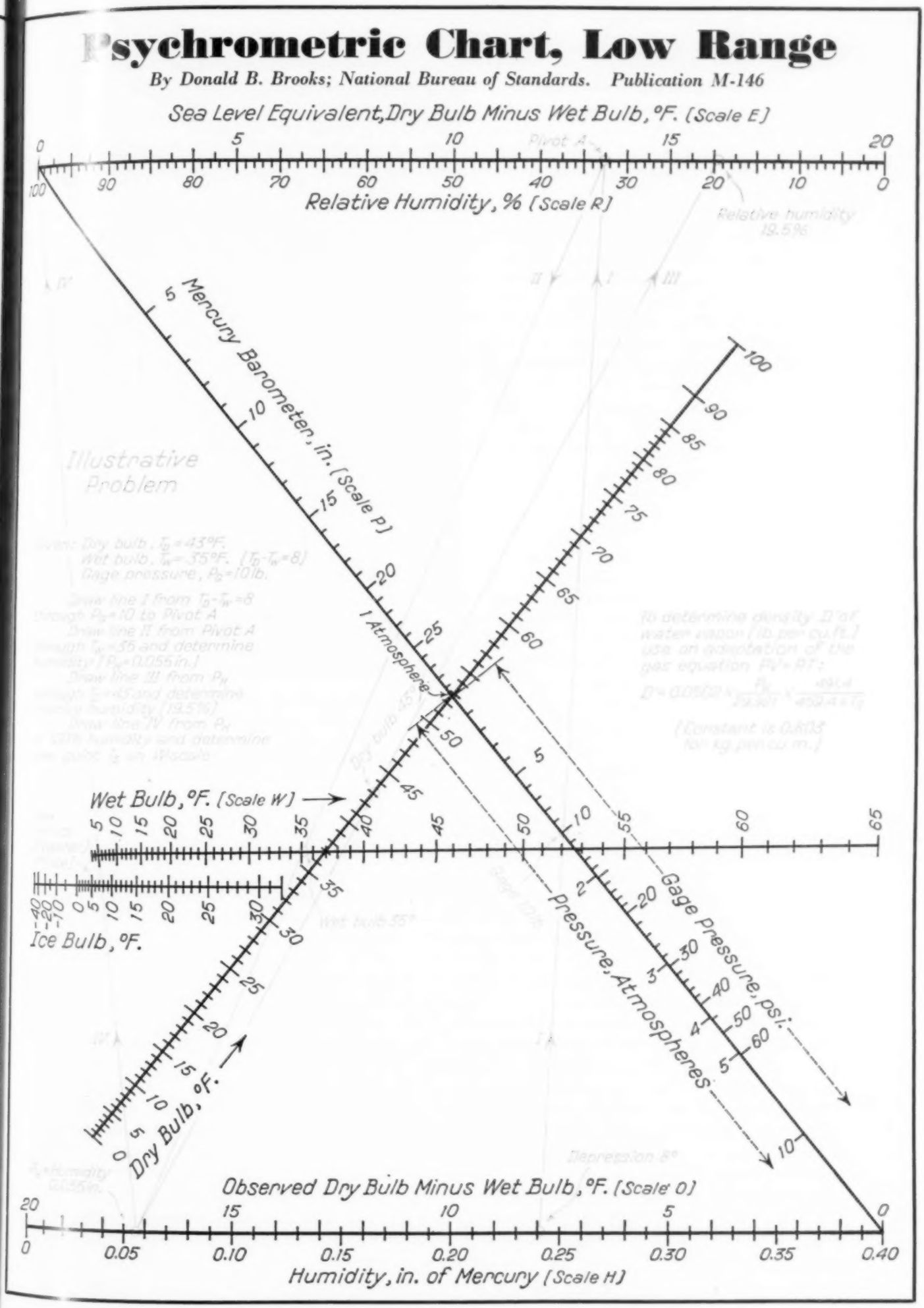
Psychrometric Chart, High Range

By Donald B. Brooks; National Bureau of Standards. Publication M-146


Sea Level Equivalent, Dry Bulb Minus Wet Bulb, °F. (Scale E)
Relative Humidity, % (Scale R)
Mercury Barometer, in. (Scale P)
1 Atmosphere
Wet Bulb, °F. (Scale W)
Dry Bulb, °F. (Scale D)
Gage Pressure, psi.
Pressure, Atmospheres
Observed Dry Bulb Minus Wet Bulb, °F. (Scale O)
Humidity, in. of Mercury (Scale H)

Psychrometric Chart, Low Range

By Donald B. Brooks; National Bureau of Standards. *Publication M-146*


Sea Level Equivalent, Dry Bulb Minus Wet Bulb, °F. [Scale E]
Relative Humidity, % [Scale R]
Mercury Barometer, in. [Scale P]
1 Atmosphere
Wet Bulb, °F. [Scale W]
Ice Bulb, °F.
Dry Bulb, °F.
Gage Pressure, psi.
Pressure, Atmospheres
Observed Dry Bulb Minus Wet Bulb, °F. [Scale D]
Humidity, in. of Mercury [Scale H]

This process has been long used for heating rivets and is particularly advantageous for end heating or other localized heating of bar stock for forging. Due to radiation from the surface, such bars when heated by normal alternating currents are usually slightly hotter at the center than on the outside, which is the reverse of the situation after heating in a forge furnace. By resistance any length can be heated, and the hot zone can be closely defined by proper spacing of the electrodes. Heating is so fast that negligible scale is formed. This process is also used for heat treating and annealing both ferrous and non-ferrous rods and tubes. Accurate temperature control can be had by either a time clock or photo-electric cell. Trouble in earlier models due to arcing and pitting under the electrodes has been eliminated by pressure grips that make contact a fraction of a second before the current starts. The stock should be free from heavy scale but does not need to have a polished surface.

Resistance heating operates best on bars or tubes having a uniform cross-section. The main advantages are speed of heating, control of temperature and heated zone, and low current consumption because no heating-up time is needed and the radiation losses are small.

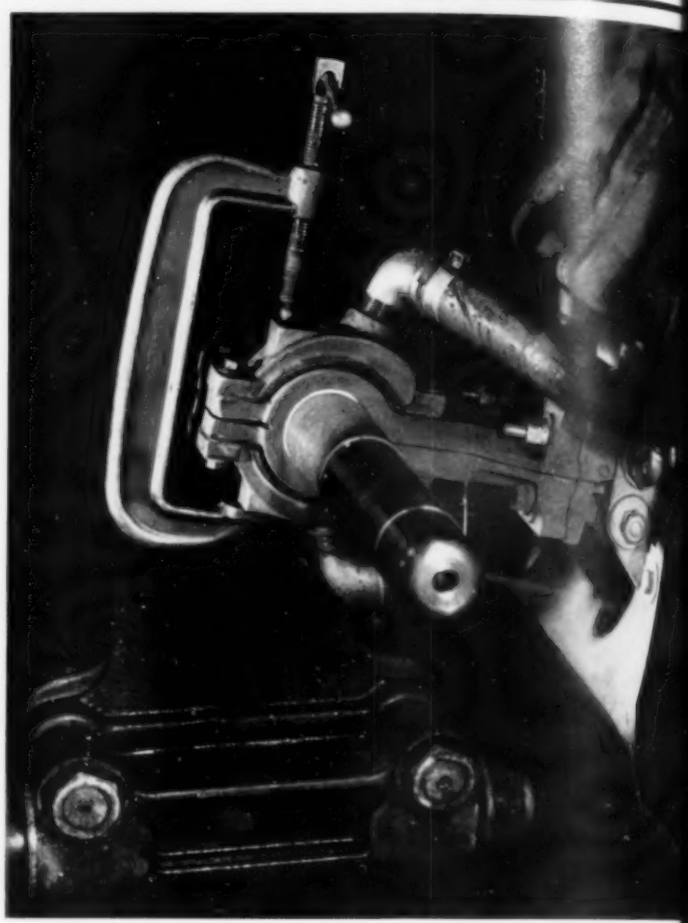


Fig. 5 and 6 — Heating by Induced High Frequency Currents [illegible] *the* [illegible] *a Rapid Operation Difficult to Photograph. In the first view* [illegible] *shaft bearing is within the fixture and its surface there is* [illegible]

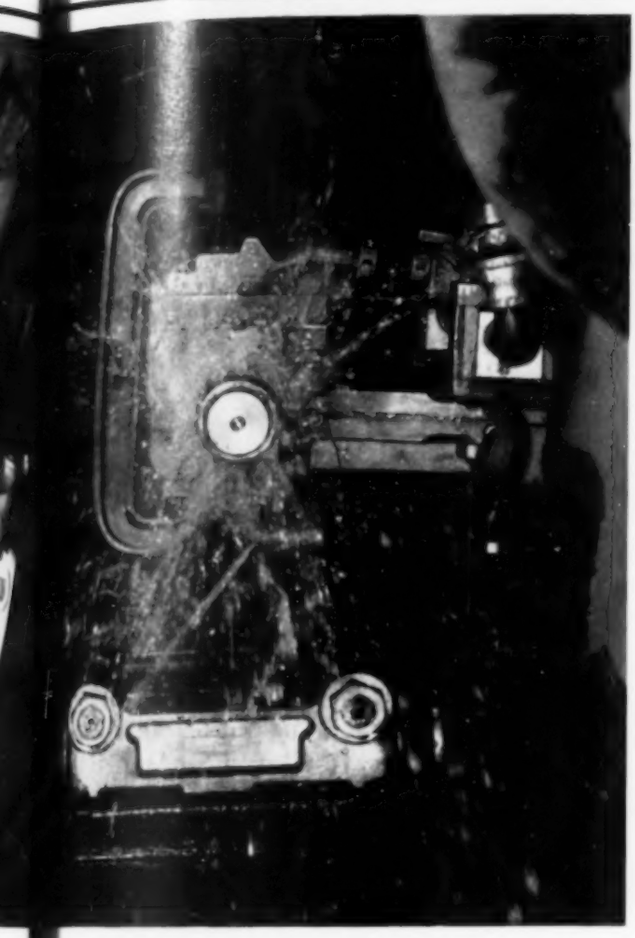
A heating process that has been known and used occasionally by several people for many years has taken great strides in the recent past. This is *induction heating*. A detailed discussion of the many results accomplished, the equipment used and the theories as to why the results obtained actually do happen, cannot be given in a paper of this nature.

The early attempts to heat inductively tried to substitute electric heat for older heating processes. It soon became apparent that the big advantages were in localized hardening. Why heat the entire part when one or two small areas properly hardened will give complete and satisfactory service? Hardening of both internal bores and external surfaces has been done in ways that amaze the production man and the designer. Properly selected steels can be surface hardened to replace carburized and hardened parts and frequently a less expensive steel can be used. If the designing engineer understands induction hardening he can often simplify and cheapen the part to make large savings in processing and assembly.

Simple, plain surfaces can be easily hardened or the inductor coil can be wound in more complicated shapes to heat many non-uniform cross-sections. Crankshaft bearings, wrist pins, camshafts, worm drives, drive shaft bearing surfaces, internal hub bearing surfaces and interior walls of tubes are only a few of the jobs that are being satisfactorily surface hardened in production today.

These electric processes all use frequencies ranging from 2000 to 10,000 cycles, and quenching is synchronized with the heating cycle so as to give a very fast quench. Consequently uniform and high hardnesses are obtained day after day. The heating time is usually a matter of seconds. Quenching takes somewhat longer than heating, but still is a short time.

The source of high frequency currents in



the next the current has been switched off and the ng water switched on. The C-clamp is a temporary nt. (Photos by Ackerman at the Ohio Crankshaft Co.)

these machines is usually a motor-generator set, whose cost has been one objection to inductive hardening. These sets, while still relatively expensive, are long lived and trouble free. The coils are easily made and inexpensive and are the only parts that need to be changed with a change in part design. This permits the cost of the equipment to be written off in two stages. Write off the motor-generator over several years, but write off the coils during the life of the part. This method may make the cost of the hardening machine less than that for a conventional furnace designed to heat the part in question.

Surface hardening requires merely the heating of the outer shell of steel, and this is ideally done by alternating currents of high frequency. However the process is also being successfully used for deep heating (complete heating) as of forging billets, especially on high production of shell. The uniform and rapid heating of forging billets has introduced economies of operation not fully realized when the job was started. The thorough heating produces a more plastic steel that completely fills the die faces with less power on the forging machine. Uniform heating also gives a good grain structure to the forging, and this is responsible for faster and better machining, and more uniform physical properties. Rapid heating has reduced the amount of scale formed, so that die wear has been greatly lessened. Heating for an upsetting or bending operation is efficient because the heat can be confined properly and bulging or movement of metal is prevented where it is not desired.

Various Frequencies Used

High frequency heating is spectacular and has many advantages but many jobs can be done with ordinary 60-cycle current. Any tubular or hollow part into which a laminated iron core (or a core of a special high Curie-point alloy) can be inserted can be heated by 60 cycles to the heat treating temperature. Solid parts cannot be successfully heated by low-cycle currents to above about 1300° F., but this opens the entire field of low temperature heating, such as tempering, heating for expanding, or stress relieving, to induction heating.

Low-cycle heating is not so fast as when using high frequencies, but it does heat throughout the cross-section. The time is short compared to radiation or convection heating, and the operation is so simple and clean that it can be done anywhere without interference with other fabrication. Starter ring gears, pistons for wrist pin assembly and other shrink fit jobs are being heated in this way. The stem ends of drive pinions and the spline ends of axle shafts are being drawn by induction. An interesting and otherwise impossible application is stress relieving of welded joints in high temperature steam piping, welded in the field in confined spaces not approachable by heat from any other source. All that is needed is to wind the joint with a copper coil that carries 60 cycle current; a temperature of 1250 to 1300° F. is readily reached which will remove stresses set up in the arc welding process.

Sixty-cycle coils are used to heat steel containers in certain chemical processes and give good temperature control and freedom from hazard to explosive contents.

The author wishes to acknowledge the assistance given by the builders and users of equipment described, although no specific credit is given.

Combustion of Common Gases

Adapted (by permission) from tables in 1940 issue of American Gas Catalog and Handbook

Material, Formula and Reaction	Molecular Weight	Specific Gravity (Air = 1.0)	Density at 60° F., 30 In. Barometer		Specific Heat (H_2O = 1.0)	Heat of Combustion				Cu.Ft. per Cu.Ft. Combustible				
			Lb./Cu.Ft.	Cu.Ft./Lb.		B.t.u. per Cu.Ft.		B.t.u. per Lb.		Required for Combustion		Products of Combustion in Air		
						Gross	Net	Gross	Net	Air	O_2	CO_2	H_2O	N_2
Carbon, C (to CO) ..... $C+\frac{1}{2}O_2=CO$	12.010	.....	.....	.....	....	.....	.....	3,958	3,958	2.382*	0.5*	1.0* CO	...	1.882*
Carbon, C (to CO_2) ..... $C+O_2=CO_2$	12.010	.....	.....	.....	....	.....	.....	14,092	14,092	4.764*	1.0*	1.0*	...	3.764*
Carbon monoxide, CO ..... $CO+\frac{1}{2}O_2=CO_2$	28.010	0.9667	0.07402	13.509	0.249	321.7	321.7	4,345	4,345	2.382	0.5	1.0	...	1.882
Carbon dioxide, CO_2	44.010	1.5289	0.11707	8.542	0.199	.....	.....	.....	.....	....	....	...	...	.....
Hydrogen, H_2 ..... $H_2+\frac{1}{2}O_2=H_2O$	2.0160	0.06951	0.005323	187.881	3.445	325.0	274.6	61,061	51,592	2.382	0.5	...	1.0	1.882
Paraffin Series, C_nH_{2n+2}														
Methane, CH_4 ..... $CH_4+2O_2=CO_2+2H_2O$	16.042	0.5548	0.04248	23.542	0.553	1,015.0	914.0	23,896	21,517	9.528	2.0	1.0	2.0	7.528
Ethane, C_2H_6 ..... $C_2H_6+3\frac{1}{2}O_2=2CO_2+3H_2O$	30.068	1.0468	0.08016	12.475	0.386	1,790	1,637	22,330	20,422	16.674	3.5	2.0	3.0	13.174
Propane, C_3H_8 ..... $C_3H_8+5O_2=3CO_2+4H_2O$	44.094	1.550	0.11866	8.427	0.365	2,572	2,366	21,675	19,939	23.820	5.0	3.0	4.0	18.820
n-Butane, C_4H_{10} ..... $C_4H_{10}+6\frac{1}{2}O_2=4CO_2+5H_2O$	58.120	2.078	0.1591	6.284	0.351	3,393	3,132	21,321	19,681	30.966	6.5	4.0	5.0	24.466
Iso-Butane, C_4H_{10} ..... $C_4H_{10}+6\frac{1}{2}O_2=4CO_2+5H_2O$	58.120	2.066	0.15815	6.323	0.351	3,364	3,105	21,271	19,633	30.966	6.5	4.0	5.0	24.466
n-Pentane, C_5H_{12} ..... $C_5H_{12}+8O_2=5CO_2+6H_2O$	72.146	2.49*	0.1907*	5.245*	....	4,023*	3,720*	21,101	19,511	38.112*	8.0*	5.0	6.0	30.112
n-Hexane, C_6H_{14} ..... $C_6H_{14}+9\frac{1}{2}O_2=6CO_2+7H_2O$	86.172	2.97*	0.2277*	4.392*	....	4,771*	4,418*	20,954	19,404	45.258*	9.5*	6.0	7.0	35.758
Olefin Series, C_nH_{2n}														
Ethylene, C_2H_4 ..... $C_2H_4+3O_2=2CO_2+2H_2O$	28.052	0.9747	0.07464	13.398	0.363	1,615	1,514	21,638	20,285	14.292	3.0	2.0	2.0	11.292
Propylene, C_3H_6 ..... $C_3H_6+4\frac{1}{2}O_2=3CO_2+3H_2O$	42.078	1.481	0.11340	8.819	....	2,380	2,226	20,990	19,630	21.438	4.5	3.0	3.0	16.938
Butylene, C_4H_8 ..... $C_4H_8+6O_2=4CO_2+4H_2O$	56.104	1.935	0.1482	6.750	....	3,079	2,877	20,780	19,420	28.584	6.0	4.0	4.0	22.584
Aromatic Series, C_nH_{2n-6}														
Benzene, C_6H_6 ..... $C_6H_6+7\frac{1}{2}O_2=6CO_2+3H_2O$	78.108	2.712*	0.2076*	4.816*	....	3,758*	3,607*	18,100(*a*)	17,370(*a*)	35.730*	7.5*	6.0	3.0	28.230
Toluene, C_7H_8 ..... $C_7H_8+9O_2=7CO_2+4H_2O$	92.134	3.177*	0.2433*	4.110*	....	4,452*	4,250*	18,300(*a*)	17,470(*a*)	42.876*	9.0*	7.0	4.0	33.876
Xylene, C_8H_{10} ..... $C_8H_{10}+10\frac{1}{2}O_2=8CO_2+5H_2O$	106.160	3.661*	0.2803*	3.567*	....	5,189*	4,937*	18,510(*a*)	17,610(*a*)	50.022*	10.5*	8.0	5.0	39.522
Acetylene, C_2H_2 ..... $C_2H_2+2\frac{1}{2}O_2=2CO_2+H_2O$	26.036	0.907	0.06946	14.396	0.383	1,491	1,440	21,460	20,730	11.910	2.5	2.0	1.0	9.410
Naphthalene, $C_{10}H_8$ ..... $C_{10}H_8+12O_2=10CO_2+4H_2O$	128.164	.....	.....	.....	....	.....	.....	17,280(*b*)	16,690(*b*)	57.168*	12.0*	10.0	4.0	45.168
Ammonia, NH_3 ..... $NH_3+\frac{3}{4}O_2=\frac{1}{2}N_2+1\frac{1}{2}H_2O$	17.032	0.5966	0.04568	21.890	0.520	442	365	9,678	8,000	3.573	0.75	...	1.5	3.323
Nitrous oxide, N_2O	44.016	1.530	0.11712	8.538	0.221	.....	.....	.....	.....	....	...	...	...	.....
Nitric oxide, NO	30.008	1.0365	0.07936	12.600	0.232	.....	.....	.....	.....	....	...	...	...	.....
Hydrogen sulphide, H_2S ..... $H_2S+1\frac{1}{2}O_2=SO_2+H_2O$	34.076	1.186	0.0908	11.013	0.245	645	595	7,100	6,545	7.146	1.5	1.0 SO_2	1.0	5.646
Sulphur dioxide, SO_2	64.060	2.2636	0.17333	5.769	0.154	.....	.....	.....	.....	....	...	...	...	.....
Water vapor, H_2O	18.016	0.6220*	0.04763*	20.995*	0.48	.....	.....	.....	.....	....	...	...	...	.....
Oxygen, O_2	32.0000	1.1051	0.08462	11.818	0.217	.....	.....	.....	.....	....	...	...	...	.....
Nitrogen, N_2	28.016	0.9671	0.07405	13.504	0.249	.....	.....	.....	.....	....	...	...	...	.....
Nitrogen ("Atmospheric") (*c*)	28.161	0.9721	0.07443	13.435	0.247	.....	.....	.....	.....	....	...	...	...	.....
Air (*d*)	.....	1.0000	0.07657	13.060	0.240	.....	.....	.....	.....	....	...	...	...	.....

Typical Commercial Gases

Kind of Gas	Constituents of Dry Gas—% by Volume								Heat of Combustion				Cu.Ft. per Cu.Ft. Combustible				
	CO_2	Ill.	O_2	CO	CH_4	C_2H_6	H_2	N_2	Specific Gravity (Air = 1.0)	B.t.u. per Cu.Ft. Gross	B.t.u. per Cu.Ft. Net	B.t.u. per Lb. Gross	B.t.u. per Lb. Net	Required for Combustion: Air	Required for Combustion: O_2	Products of Combustion in Air: CO_2	Products of Combustion in Air: H_2O	Products of Combustion in Air: N_2
Natural gas																		
San Joaquin, Cal.	0.1	...	...	...	98.7	...	...	1.2	0.560	1,002	902	23,368	21,036	9.40	...	0.987	1.974	7.442
Texas Panhandle	0.1	(*e*)	0.1	...	82.2	6.1	...	7.7	0.660	1,055	954	20,876	18,878	9.88	...	1.076	9.997	7.882
Gulf Coast	0.2	...	1.0	...	88.8	2.3	...	7.7	0.610	942	849	20,168	18,177	8.80	...	0.934	1.845	7.027
West Virginia	0.8	...	...	...	75.0	23.1	...	1.1	0.680	1,175	1,064	22,572	20,439	11.00	...	1.212	2.193	8.700
Coal gas																		
Horizontal retort	2.1	3.8	0.4	8.7	28.2	2.8	50.5	3.5	0.431	612	549	18,544	16,635	5.32	...	0.568	1.240	4.241
Horizontal retort	2.8	4.5	0.6	7.4	34.3	...	41.6	8.8	0.493	606	545	16,053	14,437	5.33	...	0.589	1.206	4.299
Vertical retort	3.0	3.1	0.6	7.0	32.8	...	50.4	3.1	0.410	587	525	18,698	16,723	5.10	...	0.527	1.231	4.060
By-product coke oven gas.	2.1	3.2	0.4	5.0	30.3	...	52.9	6.1	0.400	566	505	18,480	16,488	4.90	...	0.476	1.209	3.935
Water gas																		
Carburetted with gas oil.	3.3	10.7	0.7	33.4	10.0	...	38.1	3.8	0.651	563	520	11,294	10,431	4.76	...	0.799	0.827	3.822
Carburetted (heavy oil).	4.6	10.3	0.6	24.1	9.0	2.2	32.5	16.7	0.710	535	494	9,841	9,087	4.60	...	0.740	0.808	3.825
Uncarburetted	6.2	...	0.3	39.2	2.3	...	49.0	3.0	0.550	309	282	7,337	6,698	2.31	...	0.477	0.536	1.852
Oil gas	3.0	4.0	0.6	9.7	28.1	...	50.2	4.4	0.440	568	509	16,859	15,108	4.90	...	0.536	1.156	3.912
Producer gas																		
Anthracite coal	6.6	0.3	...	25.1	0.3	...	18.7	49.0	0.637	151	141	2,356	2,200	1.13	...	0.330	0.210	1.580
Bituminous coal	2.5	0.4	0.3	27.0	2.5	...	12.0	55.3	0.866	160	151	2,413	2,277	1.23	...	0.333	0.179	1.529
Blast furnace gas	9.4	...	...	27.8	...	...	1.0	61.8	1.006	93	92	1,207	1,196	0.69	...	0.372	0.010	1.160

Notes: *Figure calculated on assumption that substance could exist as gas at 60° F. and 30 in. of mercury.

(*a*) Liquid
(*b*) Solid
(*c*) Contains 0.94% argon by volume, about 0.03% CO_2 and trace of hydrogen.
(*d*) Purified, dry air contains 20.99% oxygen and 79.01% nitrogen and other inert gases by volume (or 23.20% oxygen and 76.80% nitrogen by weight).
(*e*) 2.4% C_3H_8, 1.4% C_4H_{10}.

Production of protective atmospheres for all varieties of heat treatment, even for high carbon, high alloy steels, hardened from high temperatures, is an outstanding achievement of the furnace industry. Mr. Segeler describes the rugged equipment devised for this purpose

Gas Furnaces

Become Modern Production Machines

Of course, the National Defense Program has tremendously accelerated the use of gas furnaces and gas heating methods of all kinds, but even if this were not the case, the latest developments in the field of gas furnaces would be worth telling about. Not that recent inventions have revolutionized present practice nor startled the metallurgists out of their present ideas on heating! Nevertheless, the news has gotten around that there is a very definite field for gas in the production line as well as in the manufacture of fine parts.

As for continuous production equipment, it is clearly a misnomer to talk about a gas "furnace" today, for the equipment is steadily losing the attributes of the furnace and more and more acquiring the characteristics of a precision production machine. Compared to the limitations imposed on products made in other furnaces, the gas equipment offers possibilities for the simultaneous control of the heating required by the product, and the protection of its surface and shape. These possibilities justify the statement in the title of this article that "the gas furnace is becoming a precision production machine".

This concept is not merely based on the effective operation of a gas furnace along expected lines of high efficiency and high rates of production. Rather, it is based on the fact that the radiant tube furnace, plus a prepared atmosphere, place gas-operated equipment in a unique position for serving the industry by giving the user a heating apparatus which will not be impaired in effectiveness by the action of carburizing or reactive atmospheres needed for modifying or protecting the work in process. Readily available case histories from some of the outstanding heat treating departments furnish factual background for this conclusion. For example, in a recent installation for the normalizing of tubing the sulphur in the lubricant remaining on the metal from the drawing dies created a corrosive atmosphere which attacked the heating elements. This difficulty was entirely eliminated by the adoption of a radiant tube, gas-fired furnace.

The *science* of metal treating has had a history of slow growth — perhaps "evolution" would be a better term for the gradual improvement of heat treating methods. In any event, there was a comparatively long period during which the physical properties of metals were raised by various forms of heat treatment, and all the while an effort was made to preserve the surfaces as much as possible even though they were in contact with crudely unregulated products of combustion. Step by step the methods

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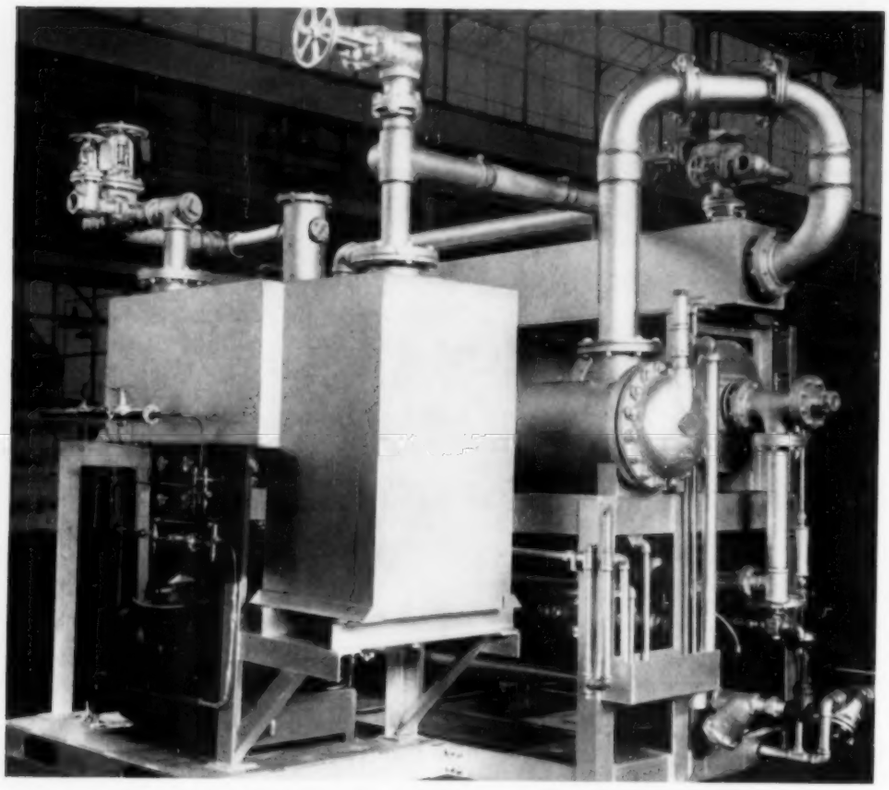
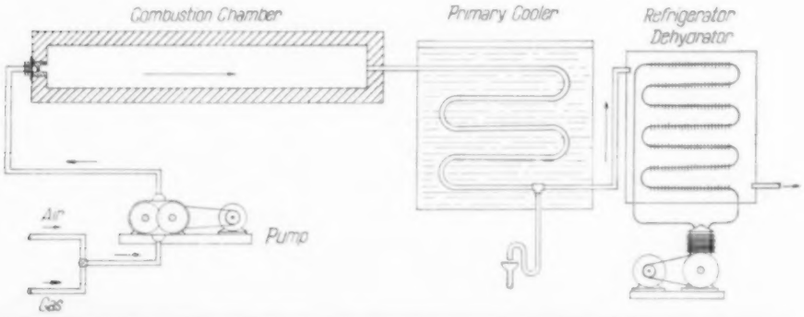


Fig. 1 — Schematic Drawing, and Typical Embodiment, of "Partial Combustion Unit". With natural gas at 40 cents per thousand cubic feet, protective atmospheres from such units will cost from 7 to 8½ cents per thousand cubic feet



were refined but, as remarked above, progress was comparatively slow. From time to time, outstanding inventions and developments accelerated the rate of improvement, and it is worthy of remark that a number of these most outstanding occasions coincided with new application of gases to the problems of heat treating.

At the time of the first world war, the batch heat treating furnace was the conventional and accepted method, but the American role as an arsenal of defense now needs mass production methods. Construction of the continuous heat treating furnaces using gaseous fuels such as the one illustrated on pages 507 to 516 solved what otherwise might then have been a serious bottleneck. Subsequent to early development, continuous furnaces have naturally been equipped with every form of fuel and heating method with great success, and the batch heat treating methods have steadily decreased in importance except for specialized applications in which quantity production is not the primary requirement.

More recently, the gas industry has made another contribution to the metallurgical improvement by means of the protective and reactive atmospheres. (This development has received continuous attention in the pages of METAL PROGRESS, and is the subject of an important symposium at the forthcoming National Metal Congress and Exposition.) Early efforts to improve the surfaces of metals during heat treatment were made by designing gas burners for maintaining constant combustion conditions, and they gave a big improvement over results obtained from crude fuel applications. In fact, even at this writing, there are many thousands of tons of metals heat treated annually in furnaces in which the atmosphere is controlled by means of the day-by-day reproduceability and adjustment of gas burners. However, the destructive effects of high concentrations of water vapor and carbon dioxide, or even oxygen, soon attracted the attention of leading metallurgists, and muffles, boxes, and other methods to exclude flue gases were widely adopted. The electric furnace had its innings because it seemed to protect the work better. Certainly it eliminated water vapor and carbon

dioxide from the hot atmosphere, but it ordinarily did not prevent oxidation and was not suitable for carburizing.

Once the need for control of the metal surfaces assumed the importance it now possesses, modern heat treating practice began, and it has revolutionized older practice and has brought about new equipment and new methods which were entirely non-existent a decade ago. In fact, the control of the surface is often more important, and it is certainly often more difficult, than the control of sub-surface characteristics which have become well-standardized and well-understood through the persistent research of metallurgists in the plant and in the laboratory. Once the underlying chemistry of the reaction between various gases and metals was formulated and understood, it became relatively easy to apply prepared atmospheres which would be more or less inert to the metal under heat treatment.

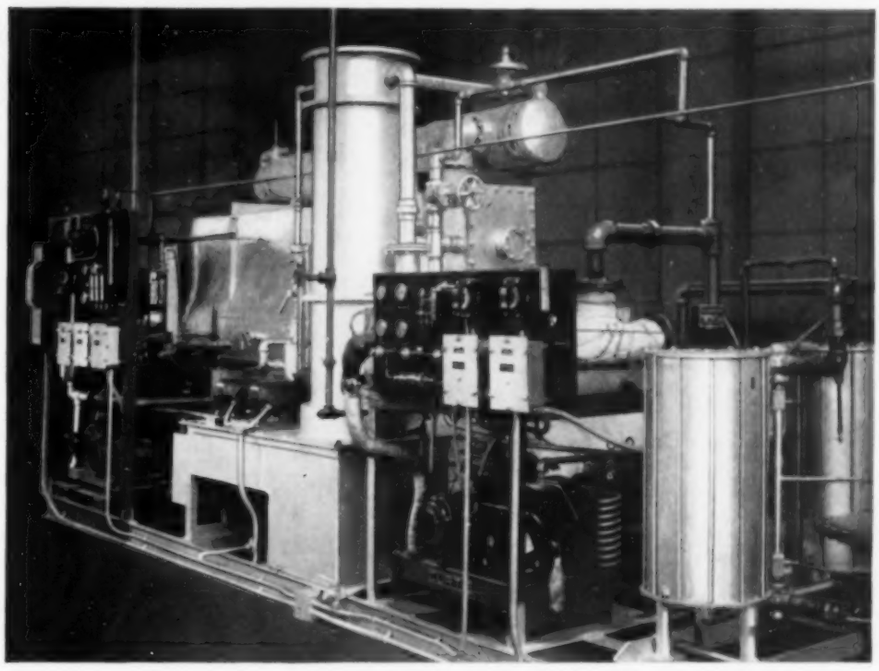
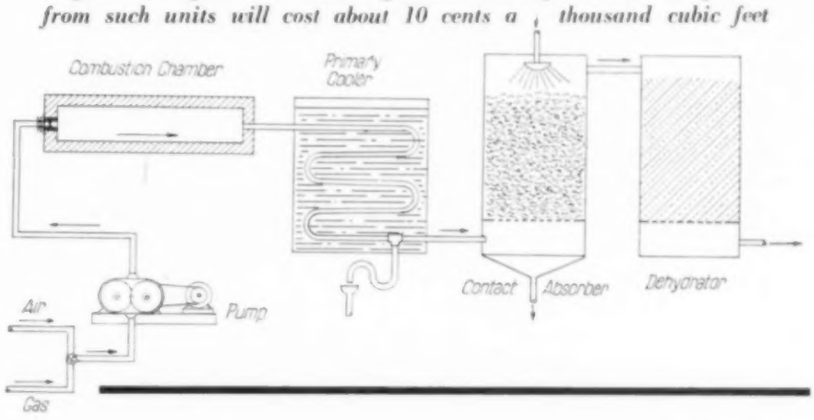


Fig. 2 — Schematic Drawing, and Typical Embodiment, of a Considerably More Complicated Device for Making a Protective Atmosphere High in Nitrogen. With natural gas at 40 cents, protective atmospheres from such units will cost about 10 cents a thousand cubic feet

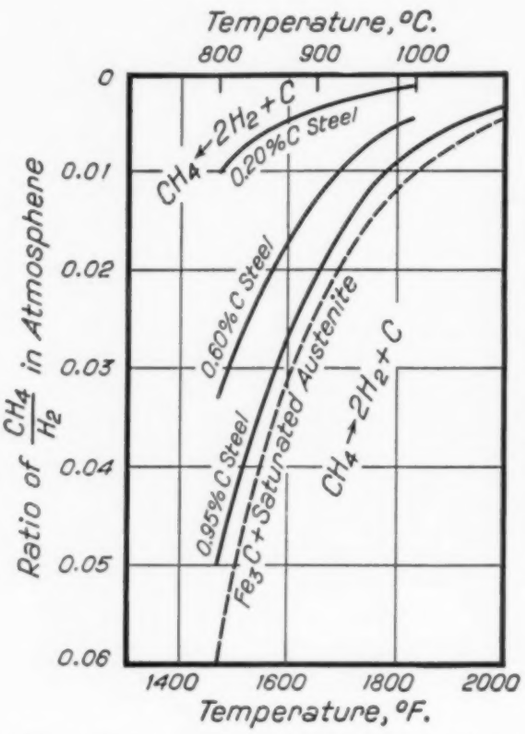


One of the first of these atmospheres was applied for the protection of sheet steels during annealing, and for this purpose, an atmosphere made by partial combustion of fuel gases was eminently satisfactory. This "partial combustion" merely required that the fuel gas be burned with a controlled but insufficient supply of air, thus producing a mixture of gases, principally carbon monoxide, hydrogen and nitrogen, with a minimum of CO_2 and water vapor. Such atmospheres after partial drying contained upwards of 70% nitrogen, and their use for bright annealing spread with great rapidity. Any of the fuel gases appeared suitable; natural gas, manufactured gases, coke oven gas, even the liquefied petroleum gases were successfully applied with or without partial purification (the latter step primarily being a dehydration by means of contact with pipes filled with cold water). Originally applied for the protection of sheet steels during annealing, this "partial combustion atmosphere" actually improved the properties of the steel surface (such as its drawability, smoothness, and ability to take a fine finish) so as to permit the development of the truly astounding one-piece, turret-top automobile and similar deep drawn articles. The so-called bright and clean annealing of low carbon steels in atmospheres of this type has all but become universal. The method and apparatus are schematically shown in Fig. 1.

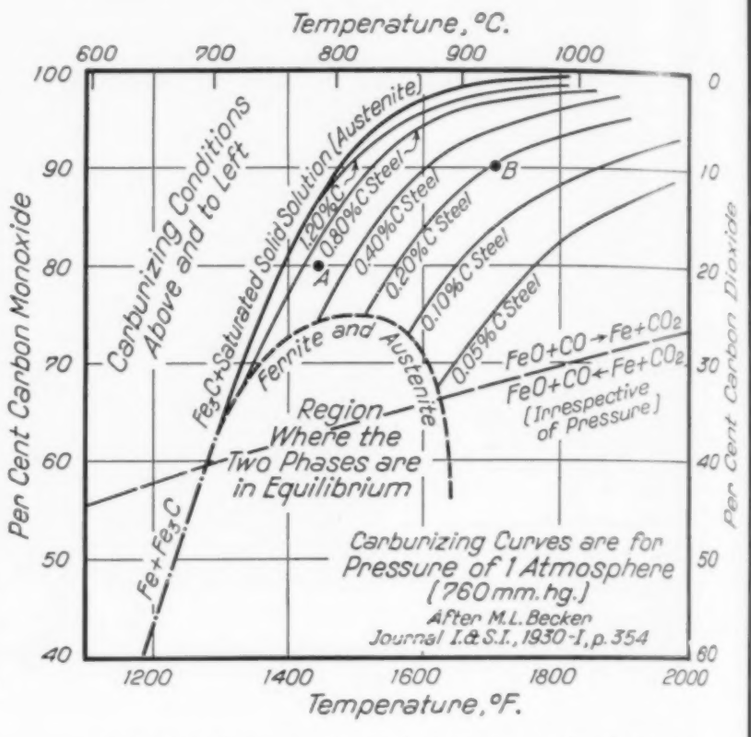
The American Gas Association's Industrial Gas Section began a research program in 1936

Equilibria for Gas-Steel Reactions

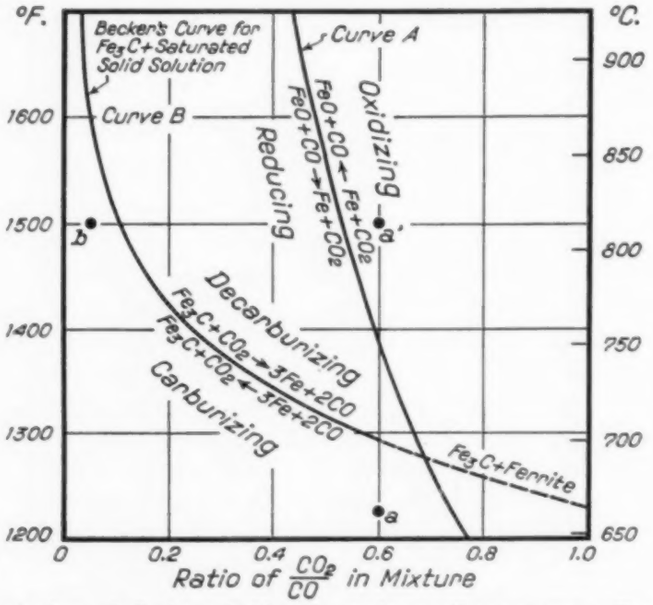
Relation Between Gas Composition, Temperature, and Carbon Content in Steel



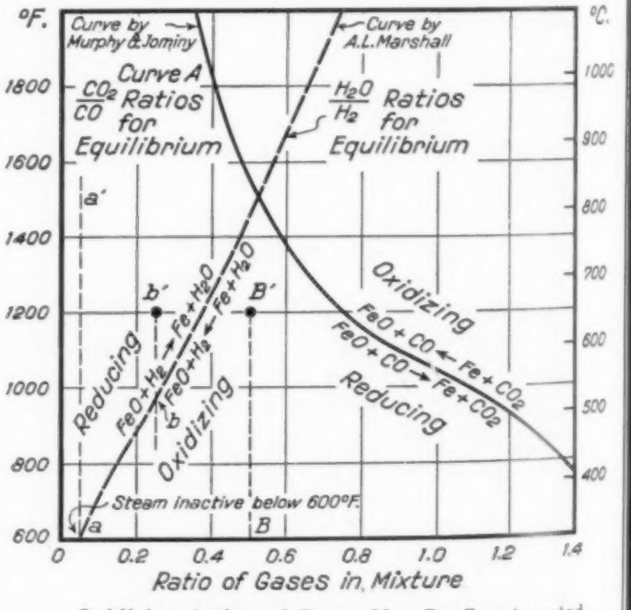
Above Curves, Adapted by Stansel From Sykes' Work, Indicate That Almost Pure H_2 Decarburizes Hot Steel (Conditions Above and Left of Corresponding Curves). Methane breaks down almost completely into carbon and hydrogen, carburizing steel (and depositing excess soot) at conditions below curves



Carburizing Reactions Depend on Carbon in Steel. Thus: 80% CO, 20% CO_2 at 1450° F., (point *A*) will carburize 0.40% C steel and lower, but decarburize 0.80% C steel and higher. However 90% CO, 10% CO_2 at 1700° F., (point *B*) is relatively inert to 0.20% C steels, will carburize lower carbon and decarburize higher carbon steels. Partial pressures, i.e., $CO + CO_2 < 100\%$, raise curves and shift to left

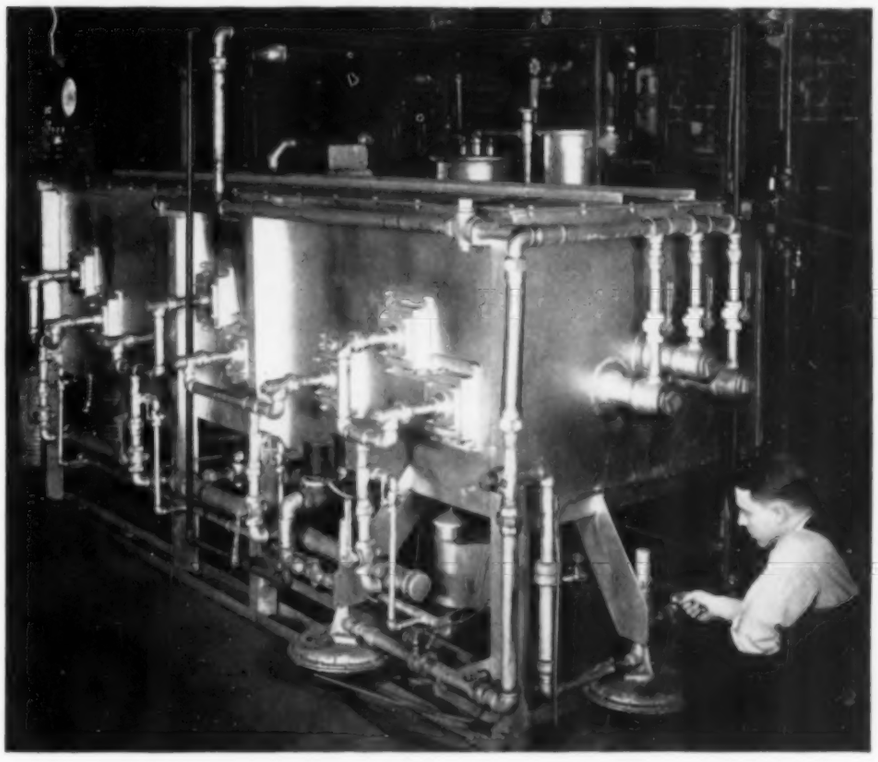


Action of Carbon Oxides Depends on Temperature. For instance, a dried atmosphere containing 6% CO_2 and 10% CO or ratio 0.6 (easily secured by partial combustion of fuel gas) would tend both to reduce and carburize at a 1225° F. anneal (Point *a*), but would both decarburize and oxidize at 1500° F. (Point *a'*). For "bright hardening" the CO_2 must be reduced well below Curve *B* (for instance, 1/10 the CO_2 as Point *b*, at 1500° F.). The above statements neglect the fact that the pressure of $CO + CO_2$ is less than 1 atmosphere



Oxidizing Action of Steam May Be Counteracted by 20 Times As Much Hydrogen (Line *a-a'*). Larger proportions of steam may scale the metal during cooling (line *b'-b*). Oxidizing — and decarburizing — propensities of moist gas may likewise be counteracted by carrying excess CO in the mixed carbon oxides present in the furnace atmosphere (for instance, $CO_2 : CO = 0.5$, or line *B-B'*, on the reducing side of curve *A*)

into reducing atmospheres produced by the combustion of industrial gas. Reports of this important work have been made to the gas industry from time to time and also to the entire engineering fraternity. See, for instance the article entitled "City Gas for Special Atmospheres" by CLINE and SEGELER in *Industrial and Engineering Chemistry* for January 1941. From results of this work we are now able to predict the behavior of gases under partial combustion conditions. Previously no one knew how the available oxygen would partition itself among the various combustible gaseous elements.



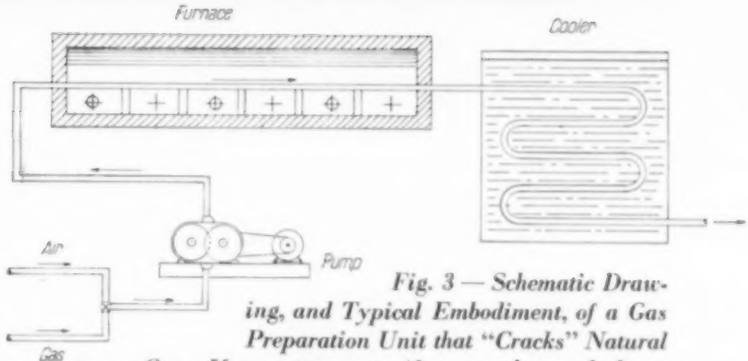


Fig. 3 — Schematic Drawing, and Typical Embodiment, of a Gas Preparation Unit that "Cracks" Natural Gas. If raw gas costs 40 cents, the cracked gas will come to about 24 cents per thousand cubic feet

Prepared High-Nitrogen Gas

Nitrogen is non-flammable, and is essentially passive to most steels, but unless it is quite dry traces of moisture left behind may react with certain steels and cause soft spots to develop. Consequently the drying of such high-nitrogen mixtures is important. Figure 2 shows a schematic diagram of equipment for producing such an atmosphere. It results from the almost complete combustion of fuel gas, followed by absorption of carbon dioxide and water vapor. The residual gas contains over 97% nitrogen, the balance being hydrogen and carbon monoxide.

While an inert atmosphere was the answer to several pressing metallurgical problems, further research and experiment were indicated because an atmosphere containing a higher percentage of hydrogen, carbon monoxide, and the hydrocarbons would doubtless produce exactly the kind of effect needed for special steels and for gas carburizing in general. This led to the third type of atmosphere known as the "cracked gas atmosphere".

This type of atmosphere, used in conjunction with the radiant tube furnaces, has come into general use for the clean hardening and bright annealing of high carbon steels. The principles underlying the unit are relatively simple. Mixtures of air and the various fuel gases in suitable proportions are passed through a series of heat-resisting alloy tubes which extend through a suitable furnace and which contain a catalyst to re-form or crack the fuel gas into the desired constituents. After suitable cooling and purification, a gas is produced in such equipment which will contain from 25 to 50% of hydrogen, 7 to 15% of carbon monoxide and 7 to 30% of the hydrocarbons. The balance is primarily nitrogen.

As can be seen from the chemical analysis, the cracking unit produces a gas richer in carbon monoxide and the hydrocarbons than can be obtained by partial combustion. These rich, cracked gases are carburizing to the low carbon steels and are relatively passive to the steels of higher carbon content. Therefore they can be applied for bright annealing, for clean hardening or for carburizing as may be required. Modification of the composition of the cracked gas atmospheres is readily done by adjusting the equipment. Figure 3 shows a schematic diagram and a photograph of a unit for producing such an atmosphere.

assure the most efficient and economical hardening. Today, research has clarified these points, and the effectiveness of proper concentrations of "buffered" hydrocarbons has been well established both in theory and in practice.

The first important industry to apply these new cracked gas atmospheres to carburizing was the automotive industry, in the person of the Chrysler Corp. in whose plant at New Castle, Ind., a large continuous-type, alloy muffle furnace was installed. Since the success of that unit, about 10 years ago, many other applications have been made. Figure 4 shows a longitudinal section of this early Chrysler furnace,

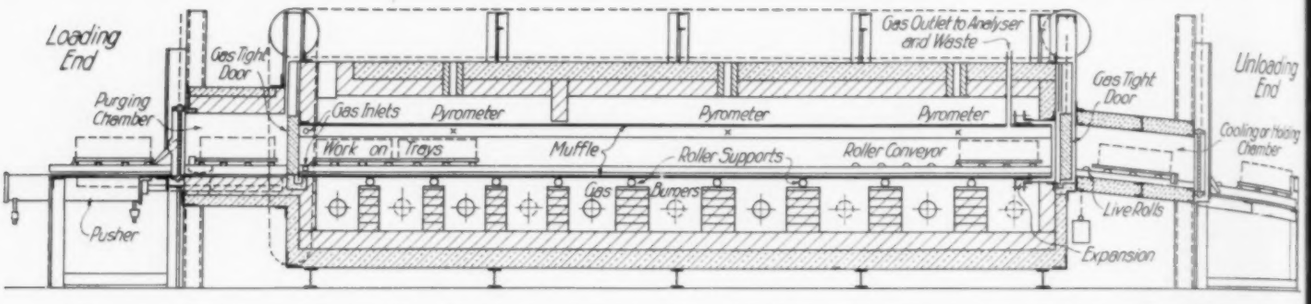


Fig. 4 — Continuous Type, Alloy Muffle, Gas Furnace for Carburizing in a Gas Atmosphere. This furnace was installed early in 1932 in the Chrysler plant at New Castle, Ind. and is one of the first applications for continuous gas carburizing. Work on trays is pushed through muffle, with "air locks" on each end. Carburizing gas enters with cool work; both progress through zones of rising temperature. Gas is controlled by automatic analysis at discharge end

Gas Carburizing

Carburizing, in particular, has been revolutionized by the availability of the radiant tube furnace and the cracked gas atmospheres. Of course, the older readers will remember the introduction of the rotary gas carburizing machine prior to the first world war. While these offered substantial economies for the hardening of small parts which could stand tumbling about, there were certain limitations which prevented the more widespread adoption of this process. However, great credit is due to the developers of the method, and the presentation of the Sauveur Medal to A. W. MACHLET last year sought to commemorate these achievements. (See the appreciative biography of Mr. MACHLET in July's METAL PROGRESS.)

The mechanics of gas carburizing were not well understood 30 years ago, nor its physical chemistry, and there were many conflicting theories regarding the way in which a gas atmosphere should be produced in order to

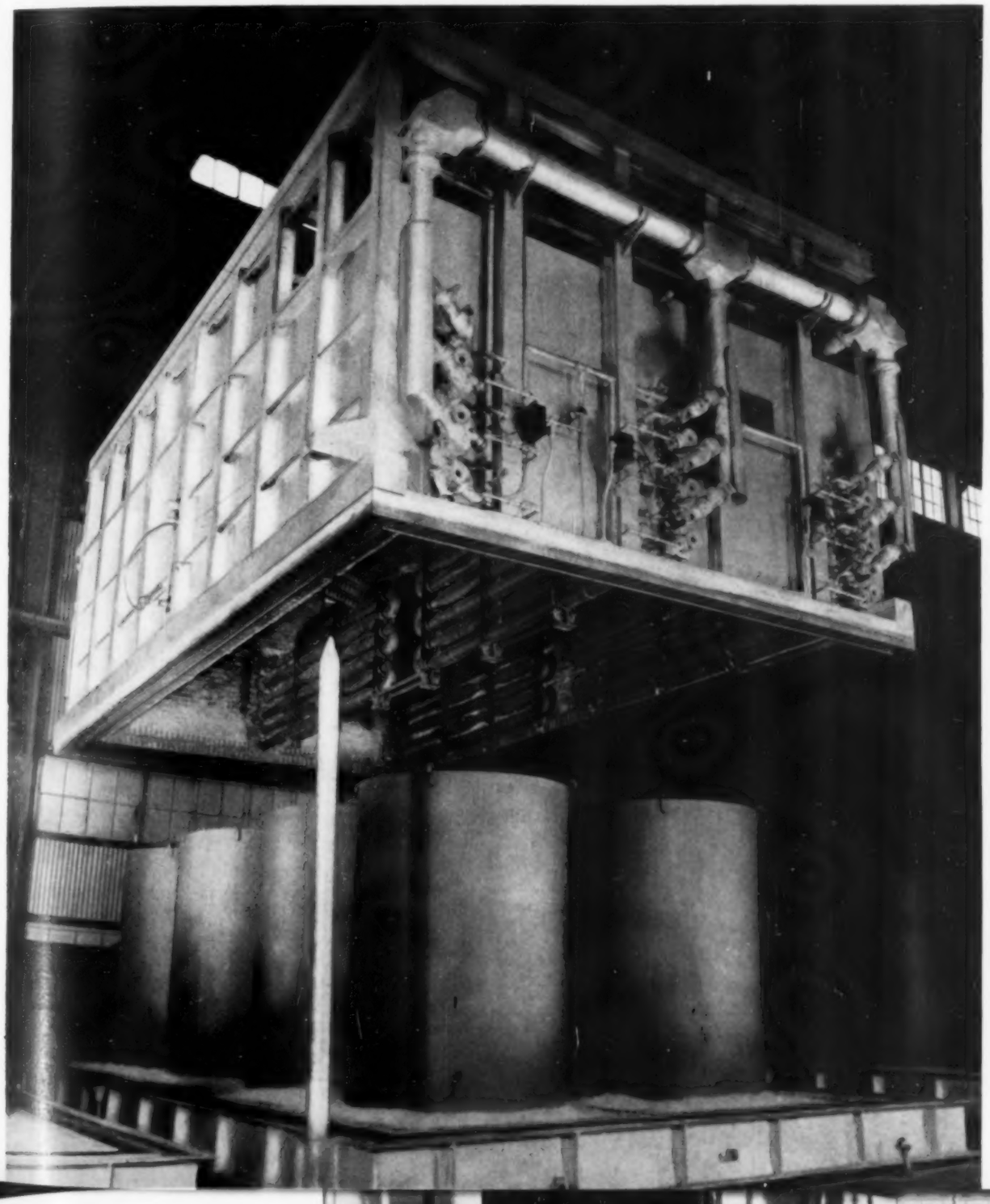
taken from an article by R. J. COWAN in METAL PROGRESS for February 1932, describing its construction and the theory of the gas actions in detail.

It is hardly necessary to dwell upon the important contribution to steel treating made by the development of gas carburizing. In the first place, it eliminated the labor cost and uncertainty of pack carburizing. So much is obvious, but what is not so self-evident is the fact that gas carburizing offers the best method of controlling the type of carburized metal produced at the surface of steel. This control is brought about by regulating the proportions of hydrocarbon gases and the buffer or inert gases used to make the activated gas mixture. Changes in the proportions of these constituents are reflected directly in the character of the carburized case that is produced — it being possible to make a low carbon hypo-eutectoid surface, a higher carbon eutectoid surface, or a still higher carbon hyper-eutectoid case. It permits that difficult feat of carburizing high alloy

steels, whose eutectoid composition may be as low as 0.70% carbon, without traces of embrittling carbide envelopes.

Because of the carburizing and reactive effects of these atmospheres, it is important that the entire furnace be engineered to withstand the action of these gases. In this respect the gas industry has made an outstanding contribution through the development of the radiant tube furnace. The importance of this point has been discussed at some length in the literature and, more recently, has been emphasized by the selection of gas radiant carburizing furnaces for producing airplane crankshafts in one of the new defense plants. In this plant, the completed engines will be block-tested while coupled to electric generators and since these are expected to produce so much power that a portion can be sold to the local utilities, it is probable that most of the other heating operations will be electric — with the notable exception of gas carburizing for the crankshafts.

Fig. 5 — Radiant Tube Cover, Above Eight Stacks of Coiled Strip Steel, Each Stack Enclosed in Thin Steel Container to Imprison Protective Atmosphere. Devices such as this have been essential to the development of continuous rolling of sheet and tin plate



Properties of Refractory Materials, Except Fireclay

Compiled by Stuart M. Phelps, and Copyrighted 1935 by American Refractories Institute, Technical Dept., Mellon Institute.

Material (1)	Composition of the Pure Material		Melting Point	True Specific Gravity	Hardness (Moh's Scale)	Mean Specific Heat (17)	Thermal Expansion (Note 22)	Thermal Conductivity (2)		
	Formula	Composition %						At 1000°F.	At 1600°F.	At 2400°F.
Andalusite	$Al_2O_3.SiO_2$	Al_2O_3 62.85 SiO_2 37.15	1810°C. 3290°F.	3.20	7.5	0.168 (18)	6.2*			
Chromite	$FeO.Cr_2O_3$ (3)	Cr_2O_3 68 FeO 32	2180°C. 3956°F.	4.5	5.5	0.22*	8.0*	10.0*	10.9*	12.1*
Corundum	Al_2O_3	Al_2O_3 100	2050°C. 3722°F.	4.0 (24)	9	0.304*	8.5	23.0*	26.5*	30.0*
Cyanite (Kyanite)	$Al_2O_3.SiO_2$	Al_2O_3 62.85 SiO_2 37.15	1810°C. 3290°F.	3.6±	4 to 7		4.9* (4)			
Diasporite (Diaspore) (5)	$Al_2O_3.H_2O$	Al_2O_3 85.1 H_2O 14.9	2050°C. 3722°F.	3.4 to 3.5	6.5 to 7	(Note 6)	6.5*			
Dolomite	$CaCO_3.MgCO_3$	CaO 30.4 MgO 21.9 CO_2 47.7	(Note 23)	2.81 to 2.95	3.5 to 4.0	0.222 (19)	14.0			
Dumortierite	$8Al_2O_3.6SiO_2.B_2O_3.H_2O$	SiO_2 64.6 Al_2O_3 28.5 B_2O_3 5.5 H_2O 1.4	1810°C. 3290°F.	3.30	7		5.2*			
Forsterite	$2MgO.SiO_2$	MgO 57.3 SiO_2 42.7	1910°C. 3470°F.	3.22	6 to 7	0.22 (19)	10.5*	11.1*	10.6*	10.3*
Graphite	C	C 100	>3000°C. >5432°F.	2.25	1 to 2	0.29	2.2			
Magnesia spinel	$MgO.Al_2O_3$	MgO 28.2 Al_2O_3 71.8	2135°C. 3875°F.	3.6	8	0.257	8.5	12.2*	13.3*	14.5*
Mullite	$3Al_2O_3.2SiO_2$	Al_2O_3 71.8 SiO_2 28.2	1810°C. 3290°F.	3.03		0.175 (20)	5.3 (7)			
Periclase (Magnesia) (8)	MgO	MgO 100	2800°C. 5072°F.	3.64 to 3.67	5.5 to 6.0	0.285	13.5*	19.5*	15.5*	13.0*
Quartz (9) (Quartzite)	SiO_2	Silica 100	1400°C. (10) 2552°F.	2.653	7	0.263*	32.6* (11) 4.6 (12)	8.8*	10.7*	13.3*
Silicon carbide	SiC	Si 70 C 30	2250°C. (13) 4082°F.	3.17 to 3.21	9 to 10	0.19 (14)	5.2 (15)	142*	110*	80*
Sillimanite	$Al_2O_3.SiO_2$	Al_2O_3 62.85 SiO_2 37.15	1810°C. 3290°F.	3.24	6.5 to 7.5	0.175				
Zircon (Zirconium silicate)	$ZrO_2.SiO_2$	ZrO_2 67.1 SiO_2 32.9	2550°C. 4622°F.	4.7	7.5	0.132 (21)	4.5			
Zirconia (Zirconium oxide)	ZrO_2	Zr 73.9 O_2 26.1	2700°C. 4892°F.	5.5 to 6.0	6.5	0.16	6.6 (16)	12.0*	13.0*	14.0*

*1. These properties refer to pure materials and not to commercial refractories which may differ because of impurities, bonding materials, and process of manufacture. The specific heat, thermal expansion and thermal conductivity data, however, may be used for engineering purposes and especially those marked with asterisk (*) which were obtained from commercial products.

2. Thermal conductivity in B.t.u. per in., per hr., per sq.ft., per °F., averaged from the more reliable data on refractories.

3. General chemical formula for chromite is $RO \cdot R_2O_3$. The RO oxide is usually FeO and may be replaced in part by MgO, while the R_2O_3 is mostly Cr_2O_3, but may be replaced in part by Al_2O_3 and Fe_2O_3.

4. Indian.

5. Commercial diaspore is composed of diasporite grains bonded with clay.

6. Probably close to 0.26.

7. Synthetic, pure.

8. Magnesite is amorphous, or crystalline like periclase, depending upon the heat treatment it has received.

9. Ganister is the commercial form for use in refractories, about 98% silica.

10. Crystobalite is the stable form of silica above 1470° C., and has the melting point of 1713° C. (3115° F.).

11. Value is for silica brick, mean expansion in range 20 to 300° C.

12. Value is for quartz, mean expansion in range 300 to 1135° C.

13. Dissociation temperature; oxidation may begin at 900° C. (1652° F.).

14. Varies with temperature.

15. This figure, and those for thermal conductivity, are for recrystallized material.

16. Pure material sintered.

17. For the range 20 to 1000° C. (68 to 1832° F.) unless noted.

18. For the range 0 to 100° C.

19. For the range 20 to 100° C.

20. For the range 20 to 800° C.

21. For the range 21 to 51° C.

22. Values for the mean reversible thermal expansion per ° C. times 10^6, for the range 20 to 1000° C. unless noted.

23. Dissociates at very high temperatures.

24. Alpha modification.

Cover Furnaces Installed With Micromax Control For Long Heating Cycles

Heat-treatment of big castings is, of course, no simple matter. But The Ohio Steel Foundry Co. can — and does — simplify the work by using highly effective heat-treating equipment. They have, for example, recently installed a battery of five 9' x 24' furnace bases, with four Surface Combustion covers, for annealing and heat-treatment of "Holl-O-Cast" and other steel rolls.

Two-point Micromax Pyrometers used by Ohio Steel Foundry Co. on S-C cover furnaces. This company has a total of about 30 L&N Pyrometers in service.

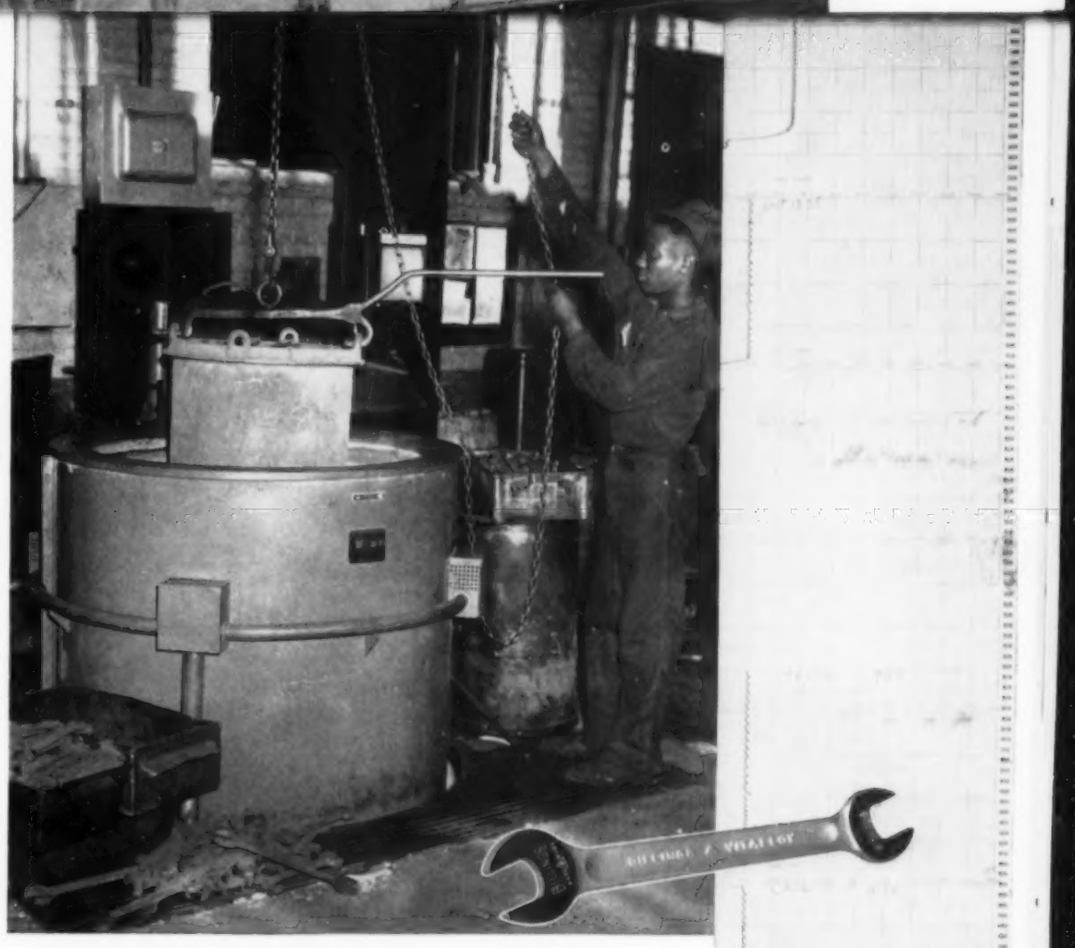
These big furnaces can follow directions for practically any heating-soaking-cooling cycle, with splendid uniformity. To provide directions which are sensitive, dependable and automatic, during the two weeks which such a cycle may require, the furnaces are equipped with Micromax Electric Control Pyrometers, used in a standard and effective way.

Each furnace has two thermocouples and two fuel-throttling valves, regulated by a single Micromax Controller. The instrument, due to its quality of micro-responsiveness, handles this setup with utmost precision. It holds temperature at the desired rate, regardless of changes in ambient temperature, fuel pressure, wind direction or any other factor. And its automatic standardizer, 50-day ink supply, 40-yard chart and freedom from any need for every-day servicing, contribute to the non-stop performance which helps assure successful heat-treatment.

For description of the various Micromax models, see Catalog N-33A, 1939, sent on request.

Picture-Minded? You'll Like This "Paper" Pyrometer

Die-stamped from cardboard, this "paper" Micromax Pyrometer shows, almost as well as the actual instrument, the qualities of convenience, accessibility and simplicity. It's made up of exterior and interior photographs printed on cardboard, died out and hinged together to represent the instrument. It will be sent, with our compliments, on request; ask for Die Out ND(1).



REJECTIONS "NEGLIGIBLE" IN HOMO TEMPERING

Tempering which is uniform and practically rejection-free is a problem no longer in the plant of Billings & Spencer Company, Hartford, Conn. Here are made tons of precision aircraft forgings, commercial forgings and Billings Vitalloy and Carbon Steel Wrenches, with hardly a reject which can be charged to tempering.

These results are achieved by using the Homo Method of tempering on all work. The electric heat, the forced-convection air and the fully-automatic control which the Method employs create a uniformity of temper which is far inside most specifications. Supervision of the work is extremely easy — an advantage always; but today a necessity. And the equipment runs with minimum attention, 24 hours a day, 7 days a week.

The Homo Method is described in Catalog T-625, 1938 edition, which will be sent on request. If you have a specific tempering problem, we'd be glad to have you outline it, since we may be able to suggest a solution based on our experience as pioneers and developers of air-tempering.

This smudged strip of Homo-Method chart, reduced to about ¼ actual size, shows how Billings & Spencer heat-treaters write down the part number, etc., of each heat, alongside its temperature record. These notes are easy to jot down because the chart, in the Recorder, is backed up by a metal plate and offers a firm, vertical surface on which to write.

LEEDS & NORTHRUP COMPANY, 4927 STENTON AVE., PHILA., PA.

LEEDS & NORTHRUP

MEASURING INSTRUMENTS . TELEMETERS . AUTOMATIC CONTROLS . HEAT-TREATING FURNACES

Jrl Ad ENT-0600C(31)

Some Notes on Refractories

IMPROVEMENT of refractories, at the present instance, appears to be of far less interest than *supply*. However it should be evident that even in times of great stringency — especially so, in fact — a better material will conserve supplies because it lasts longer. Consequently, efforts to put quality into new refractories, and further efforts to maintain them properly in service, should be unremitting.

Fortunately we have, within the United States, abundant sources of raw materials for the common metallurgical refractories, with the exception of chromite. Even this exception would not hold if we regard the Philippine Islands as "United States". Authoritative statements have been made that there is at least 12 months' supply of chromite (refractory grade) on hand; unfortunately, however, the material has no known substitute and there are practically no "non-defense" uses which can be eliminated.

Sentry Answers Moly Again!

A New Larger Furnace with *Packaged Atmosphere*

For larger tools—for increased hardening capacity—use the new No. 4Y Sentry Furnace with Sentry Diamond Block Controlled Atmosphere. For *all* high speed steels—Molybdenum—Cobalt—Tungsten—this correct neutral atmosphere means maximum hardness—No scale—No reduction in size—No decarburization. Get more production from better hardened tools.

See It Booth 8
National Metals Exposition or Write for Bulletin 1024A

DIAMOND Block

A full range of sizes for this as well as other Sentry Furnaces

Sentry "Always on Duty"

The Sentry Company
FOXBORO, MASS., U. S. A.

Blast Furnace Linings

The enormous increase in blast furnace output during a single campaign is due not only to the increased daily output from the larger stacks but also from the greater durability of the linings. WM. A. HAVEN, at the May meeting of the American Iron and Steel Institute, noted that in 1880 a run of 105,000 tons of pig iron from a single lining was claimed as a world's record. Twenty years later 500,000 tons was considered good. By 1920 the standard had been doubled, but now "furnace after furnace has made more than 1½ million tons and several have gone more than 2,000,000 and still going strong".

Chemical disintegration of the lining brick has been a most prolific cause of trouble, but finally the refractories industry has been able to produce a dense brick of proper texture, free from laminations, burned at a high temperature, that resists carbon penetration, attack by zinc fume, and other agencies. More accurately sized brick and careful mason work have also been factors in this improvement.

Much brick damage has been done by "channelling" of the blast up chimneys of coarse charge — matters which have been corrected by revolving top stock charging bells, and the

(Continued on page 594)

HARDEN
MOLY
HIGH SPEED STEELS AS EASILY AS
18-4-1
with
ELECTROTHERMIC-PERMEATION

HIGH-SPEED Tool Steels of half Molybdenum, half Tungsten or even *all* Moly are now being hardened with absolute certainty of uniform results. The Upton Electrothermic-Permeation principle of operation has made the changeover from 18-4-1 types surprisingly easy and there is very little experimenting to determine proper temperatures and time. Once determined, results can be duplicated with absolute certainty.

Users of Upton Electric Salt Bath Furnaces have found that:

1. There is no decarburization—even on ALL-MOLY alloys and size change of tools during hardening is under perfect control. This means that thousands of Moly hobs — hardened in Upton furnaces—are being sold without any grinding after hardening.
2. Properly hardened Moly H. S. Steel tools will give identical cutting characteristics with 18-4-1.
3. The ceramic pots last longer and the furnace costs considerably less to operate.

The Electrothermic-Permeation principle of operation assures a *positive,* yet natural, circulation of heated salt so strong that it supplies heat uniformly to all portions of the work. High operating efficiencies have saved upwards of $1200.00 per year in fuel alone.

With its ultra-sensitive heat input control, the Upton high heat furnaces operate within minimum temperature fluctuations. Proof of this is that re-orders of Upton furnaces have increased sharply since users have begun hardening the MOLY types of high speed steels.

Let us tell you more about these furnaces now.

SEND FOR THIS FOLDER *Today!*

Our engineering department will gladly assist you in the selection of the correct heat treating equipment for any operation requiring from 300° to 2500° F.

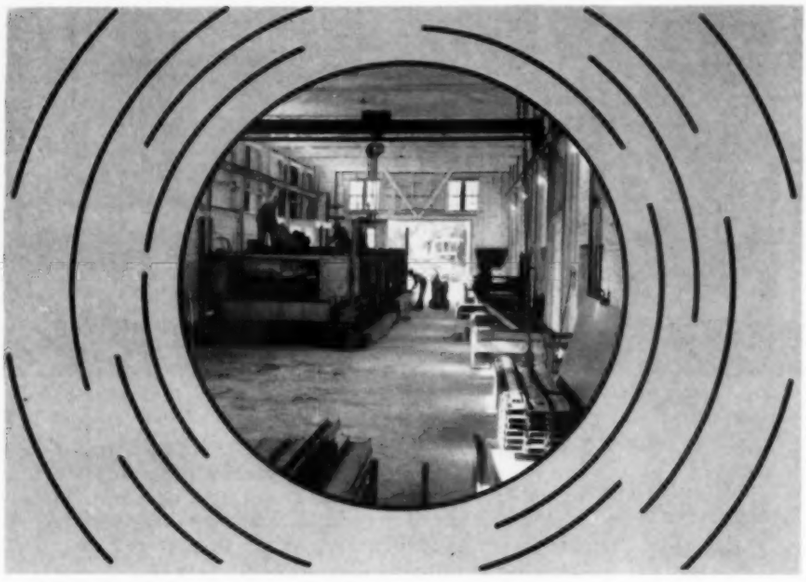
UPTON ELECTRIC SALT BATH FURNACE DIV.
Commerce Pattern Foundry & Machine Company

7452 Melville at Green
Detroit, Michigan

Refractories

(Continued from page 584)

crushing of hard, lumpy ore and flux. Armored stock line wearing plates, and improved types and arrangements of stock cooling plates, have also been important factors in lengthening the campaigns. The evils of hard driving or overblowing have also been greatly lessened in the modern 1000-ton furnace, with its bigger hearths and straighter boshes. Break outs through the bosh are fortunately now quite rare "due to a long list of improvements which include better coke, better refractories, better hearth and bosh design and construction, better application of hearth and bosh cooling, and the high pressure clay gun."



Ever-Widening Circles of Prestige for

CIRC-AIR HEAT TREATING EQUIPMENT

To meet increasing demands for CIRC-AIR furnaces, we are enlarging our manufacturing facilities as shown above.

With increased personnel and larger quarters, we are furnishing CIRC-AIR Units for all heating operations — 250° to 1350° F. These Units are used in the following industries: AUTOMOTIVE—For Drawing, Bluing, Soldering, Cast Iron and Welded Parts, Stress Relieving: ALUMINUM—For Hardening, Normalizing, Drawing, Billet Heating for Extrusion and Forging: BRASS—For Annealing, Coloring, Sweating and Soldering.

They are available in a wide range of sizes to meet varied production requirements from 200 to 20,000 lbs. per hr.

Send for "CIRC-AIR" Bulletin No. 6 today.

CIRC-AIR HEAT TREATING EQUIPMENT

INDUSTRIAL HEATING EQUIPMENT CO.

3570 FREMONT PLACE • DETROIT, MICHIGAN

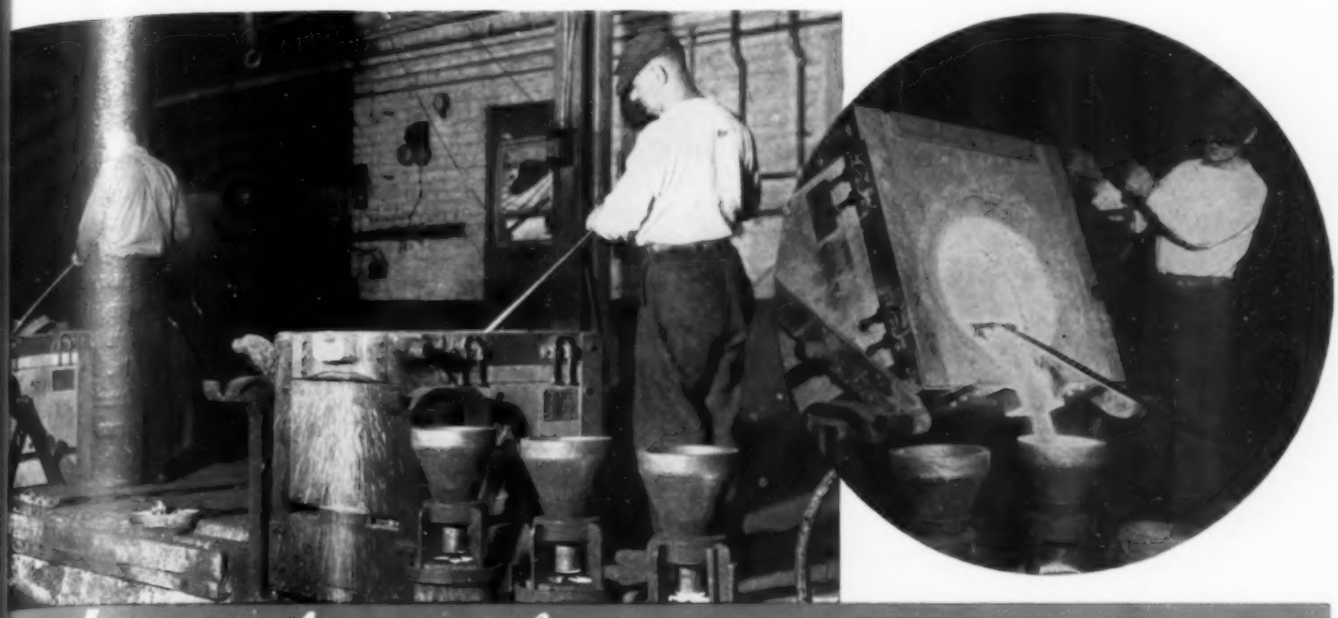
Chrome-Magnesite Mixes

Considerable work has been done in the study and improvement of ramming mixes and packaged goods (metal-cased brick). Investigations of reactions at high temperatures are difficult to conduct in such a way that the materials are not contaminated by their containers. Equilibrium conditions frequently take days or even weeks to approach; *trends* of the reactions are therefore the most that may be expected. These trends depend a great deal on temperature, for only the fluid portion of the mix reacts with appreciable velocity. Viscosity of the fluid portion at a given temperature also varies greatly — this is supposed to be the reason why MnO is so much more reactive (has so much more "fluxing power") than FeO at say 2300° F., despite the opposite indication of the theoretical studies.

In addition to these factors, the porosity, permeability, uniformity, rate of motion of the slag or scouring element, temperature irregularities, imposed load, and type of mortar all influence the rate of attack. Consequently all scientific studies must be verified by actual experience with furnace installations.

"Synthetic" refractories of chromite and magnesite have been utilized, and generally find many applications in openhearth construction where they are more durable than silica shapes. The chrome ore used in these chrome-magnesite brick is usually quite a complex mixture of minerals — chromites of various Cr:Fe ratios, aluminates, and magnesium silicates such as serpentine and talc. The latter are responsible for the relatively low strength of chrome brick under load, for they form low-melting silicates, and for this reason the addition of magnesia is of great help as it increases the viscosity of this liquid, and

(Continued on page 606)



You can quote me— **"AJAX-NORTHRUP INDUCTION FURNACES TAKE ALL THE ARTISTRY, HOCUS-POCUS AND EVEN LUCK, OUT OF THE PICTURE . . .**

ALLOY PRODUCTION IS NOW A SCIENCE WITH SPEED AND PRECISION...

and we can duplicate at any time"

STRIP
SHEET
RODS
WIRE
CASTINGS

for

DRIVER-HARRIS ELECTRICAL HEAT-CORROSION RESISTING ALLOYS

•

ASK FOR THE AJAX-NORTHRUP BULLETINS

Those are the exact words used by the Works Manager of the Driver-Harris Company, of Harrison, New Jersey, when asked his opinion of the value of AJAX-NORTHRUP Furnaces.

And he went on to say, "Our reputation is based not only on our ability to pioneer in the discoveries of new heat-corrosion resistant alloys, but to continue to deliver consistent analyses day after day and year in and out.

"The AJAX-NORTHRUP Furnace is the scientific tool that enables the metallurgist to express the quality of his fondest imaginations, in terms of the actual delivered product. It is the only furnace where the alloy is completed in the furnace and not in the ladle.

"We use it for strip, sheet, rods, wire and castings. Spare furnaces with different shells are inexpensive and enable us to make quick shifts in production."

SEE AJAX AT THE METAL EXPOSITION, BOOTH 211 AJ 338

AJAX-NORTHRUP MELTING FURNACE CAPACITIES: ONE OUNCE TO EIGHT TONS

AJAX ELECTROTHERMIC CORPORATION

AJAX PARK · TRENTON · NEW JERSEY

ASSOCIATE COMPANIES

THE AJAX METAL CO., *Non-Ferrous Ingot Metal for foundry use.*
AJAX ELECTRIC FURNACE CORPORATION, *Ajax-Wyatt Induction Furnaces for melting.*
AJAX ELECTRIC CO., Inc., *Ajax-Hultgren Salt Bath Furnace and Resistance Type Electric Furnaces.*

Refractories

(Starts on page 584)

forms spinel and forsterite crystals, to the great improvement of the refractory qualities.

The principal trouble with chrome-magnesite refractories, according to J. F. HYSLOP's paper before the West of Scotland Iron and Steel Institute (quoted in *Blast Furnace and Steel Plant* for August 1941) has been their troublesome reaction with iron slags. They expand, and in extreme cases completely disintegrate. The usual explanation is that iron oxide has been taken up in solid solution in the chromite particles, with consequent increase in volume. Microscopic and X-ray evidence shows that this action must be limited to the outer layers. The evidence rather supports the view that the harmful reactions are due to migration of magnesium atoms. It would seem that the liquid iron oxide, penetrating the pores of the brick, picks up magnesium, aluminum and chromium from the refractory materials, thus becoming much more refractory; however it tends to form and precipitate crystals of high melting point. This growth of new crystals within the pores is probably the disrupting element.

Super-Refractories

Refractories with great heat resistance have been made of alumina-silica mixtures high enough in alumina to produce the mineral mullite (72% Al_2O_3) or even much corundum (pure Al_2O_3). However in practical applications these very refractory minerals are cemented together by less desirable glasses, and failure has often resulted from intergranular attack of this bonding material. Hence the recent efforts to minimize the amount of this extraneous substance. This is being done commercially in three ways.

First, and earliest, is the now well-known method of casting. A mixture of pure ingredients is charged into an electric furnace and melted under heavy arc from carbon electrodes. Pouring temperature is about 3500° F. Molds are of clean sand, and are buried in sand so the casting cools very slowly. While the chemical analysis of a piece of cast "mullite" may be the same as a brick made and fired in the conventional way, it has a porosity of 3% compared with say 25% for the brick. Microscopically the casting may contain 20% of alundum crystals and a little interstitial glass in addition to the mullite; the structure is naturally brittle to mechanical and thermal stress.

A material called "Siemensit"

(Continued on page 613)

WE ARE BUILDING DETROIT ELECTRIC FURNACES
THREE SHIFTS . . . 24 HOURS A DAY . . .
FOR AMERICA'S DEFENSE PROGRAM

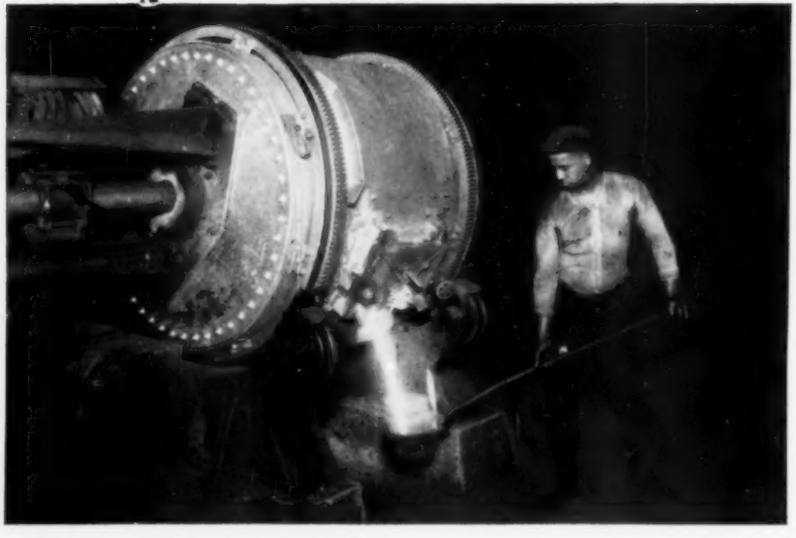
The Detroit Automatic Rocking Electric Furnace was born during World War I to meet the need for a really efficient, fast melting furnace that would conserve the nation's fuel and metal deposits.

Today these furnaces are again playing a vital part in America's Defense Program.

We are busy building Detroit furnaces 24 hours a day, to the limit of our capacity, in the effort to keep up with the steadily increasing demand.

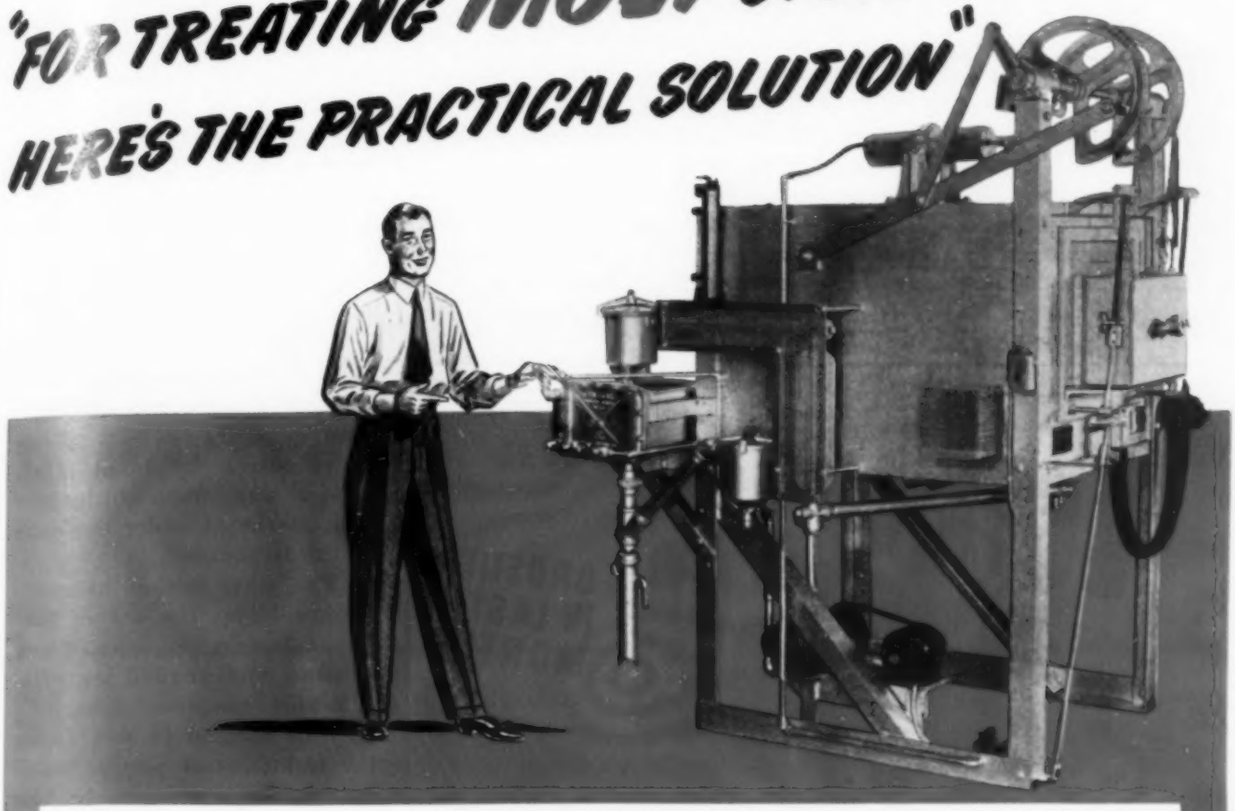
These furnaces are used for melting many different types of metals and alloys including Navy "M," Navy "G," aluminum and manganese bronzes; high speed, stainless and heat resistant steels; alloy grey irons, short cycle malleable, nickel, monel metal, etc.

The Detroit furnace produces a large number of heats, large or small in rapid succession with a minimum of maintenance. For versatility, production speed, control of composition, low labor costs, low metal loss, and all-around economy, you cannot beat a Detroit Electric Furnace. Write today for complete facts and prices or see us in Booth E50 at the National Metal Show, Philadelphia.



DETROIT ELECTRIC FURNACE DIVISION
KUHLMAN ELECTRIC COMPANY • BAY CITY MICHIGAN

"FOR TREATING MOLY STEEL HERE'S THE PRACTICAL SOLUTION"



"THIS 'CERTAIN CURTAIN' UNIT PRODUCES AND MAINTAINS THE IDEAL ATMOSPHERE"

As in so many other controlled-atmosphere applications, Hayes "Certain Curtain" control has again provided the most successful *practical working* atmosphere — this time for moly steel which has become so important in the national Defense Program. Six years ago we started work on this particular problem, with the result that today Hayes users are in an enviable position, able to shift over to moly steels smoothly, without loss of precious production.

ELECTRIC CERTAIN CURTAIN FURNACES

If moly is constituting a problem in your plant — or if ANY controlled-atmosphere job is on your mind — get in touch with us by mail or at the Show. We are eager to serve you, and can schedule priority orders for very early 1942 delivery.

C. I. HAYES, INC., Est. 1905, PROVIDENCE, R. I.

R. G. HESS, 92 Liberty St., New York
E. F. BURKE, 4614 Prospect, Cleveland
J. E. FIGNER, 6388 Penn. Ave., Pittsburgh
C. A. HOOKER, 202 Forest Ave., Royal Oak, Mich.
W. G. PRAED, 4939 N. Talman Ave., Chicago

HAYES WILL BE AT THE METAL SHOW, BOOTH C-34

World's Leading Controlled-Atmosphere Furnace

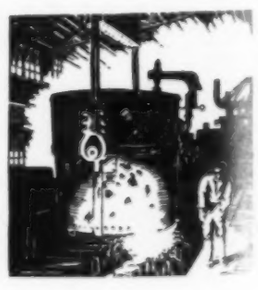
Refractories

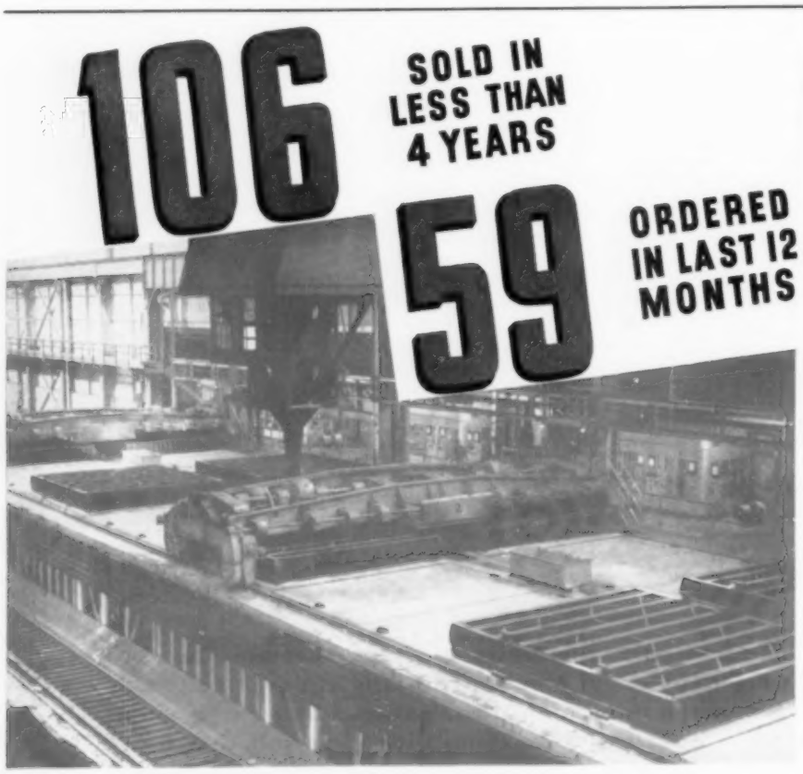
(Starts on page 584)

is being made by a similar process in Germany, and has given considerable satisfaction in simple shapes for basic openhearth linings and burner port blocks. When examined under the microscope it contains about 80% spinel, about 10% of an unidentified mineral and 3% of intergranular glass. It does not soften below 3200° F. under load. It is said to be made of mixtures of chromium oxide, magnesia and alumina in approximately equal parts.

J. H. PARTRIDGE has described two other methods of making alumina refractories without extraneous bonds in a talk before the London section of the British Institute of Metals (reported in *The Metal Industry*). One is the casting from fluid slips. Alumina is very finely ground in water, and to the settled "mud" is added a little hydrochloric acid. The hydrogen evolved by the slow attack on impurities is responsible for a creamy suspension, and this is poured into plaster of paris molds. The "cast" (usually in the form of thin-walled crucibles or dishes) is dried, and fired at 3000° F. Shrinkage is high (20% at 3200° F.) but the laboratory ware is highly resistant to corrosive attack by fused alkali, glass or slag. Such articles have been marketed under the name of "sinterkorund".

The other method of manufacture is by the use of temporary bonding agencies. Finely ground and graded material (alumina, magnesia or steatite) may be molded in dies (using the technique of powder metallurgy); the bond may be flour paste or metal hydroxides which decompose during firing. If the grinding is sufficiently fine and the size distribution of particles correct, even these bonds may be dispensed with, as the dry compact has sufficient coherence to withstand gentle handling until it is fired. Re-entrant spaces in these molded articles are provided by paper inserts, which later burn away. One advantage of these compacts of dry powders is their high accuracy and very small shrinkage during firing; they are favored for electron tube manufacture in places where high electrical resistance at high temperature is needed.





Industry goes "all out" for AMCO Pit Furnaces

When introduced four years ago, AMCO Pits established new production, fuel, maintenance and other unprecedented records for ingot-heating.

Today, because of continued refinements and improvements, AMCO Pits provide even greater over-all economies ☆ ☆ ☆ ☆ ☆ PLUS 10% further increase in production.

The AMSLER-MORTON COMPANY
FULTON BUILDING • PITTSBURGH, PA.

The expert metallurgist may easily be confused by electronic gadgets and promotional claims for a multitude of control devices, so Major Behar has, in the following article, done a useful job in classifying their fundamental elements, and pointing out certain inherent limitations

Instrumentation

Chief Trends and Some New Data

As on previous occasions, the Editor of Metal Progress planned this Instrumentation Section along broad, far-reaching lines, refraining from laying down rigid specifications as to the period reviewed ("last five years ... no reason for setting a definite time limitation"), as to the scope ("instruments which are used by metallurgists or whose application is supervised by them"), and as to the length ("article you gave us some years ago perhaps longer than necessary"). Somehow, the recipient of his invitation was made to feel like an honored guest rather than a victim!

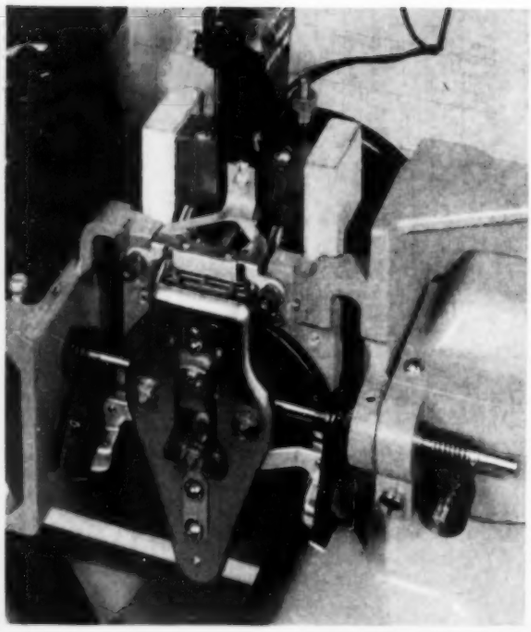
An added ingredient of the invitation was an implicit and unobtrusively flattering allusion to the value of the requested article to the national defense. An effort will be made, therefore, to select the most significant recent trends, to interpret some of them, to suggest immediately realizable possibilities, and to avoid a more-or-less lifeless catalog of things. This year, moreover, an awareness of the priorities situation should prevent writers of engineering reviews from devoting too much space to some of the most sensational new developments—which the great majority of readers cannot obtain at any price.

Broadly reviewing the field of instrumentation, the outstanding example of such a significant development during the last five years is a radically new design and construction of electrical "movement". It is of interest to metallurgists for two reasons: *(a)* It has been made possible by one of the major metallurgical advances of the last five years, namely new magnetic alloys; and *(b)* the new "movements" can serve as ammeters, voltmeters, wattmeters, milliammeters, millivoltmeters in the innumerable classes, types and varieties of metallurgical measurement and control devices. They revolutionize both direct and alternating current measurements incidental to the proper control of metallurgical operations.

It is reported that the entire output of the most widely utilized models goes to the navy yards and aircraft plants with highest priority. It is an easily verifiable fact that the orders now being accepted are for delivery at future dates which are expressed not in weeks but in months . . . or years! This is true also of some specialized types of testing machines, measuring instruments and automatic control systems made by various types of manufacturing companies ranging from specialized instrument makers to large corporations with instrument and meter departments.

As a whole, firms in the industrial instrument industry enjoy high priorities. The writer

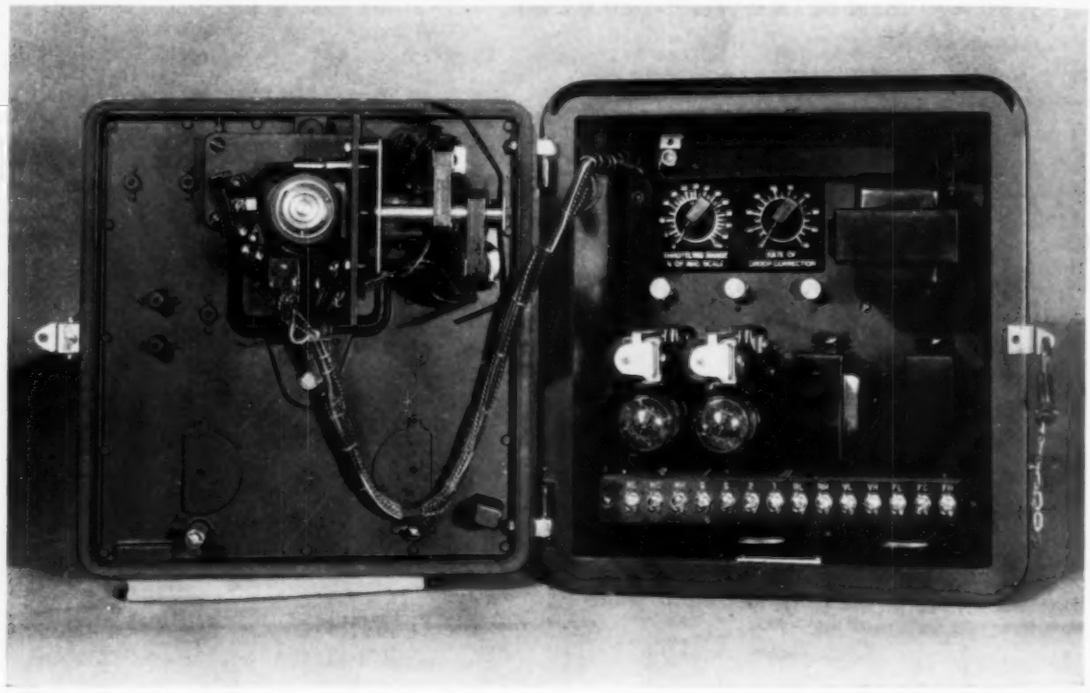
By M. F. Behar
Editor of "Instruments"
Pittsburgh, Pa.



Essential Units of Leeds & Northrup's Electric Valve Control Are the Micromax Mechanism (Left), Electric Control Unit With "Droop Corrector" (Center), and Valve Drive Mechanism (Bottom). Micromax motor and valve motor both drive slide wires in circuit with opposite legs of a secondary potentiometer bridge; when the first motor unbalances the circuit of this bridge it also actuates a relay to energize the valve-drive motor, which moves far enough to bring the secondary circuit back in balance. Consequently the micromax and valve motors move in step

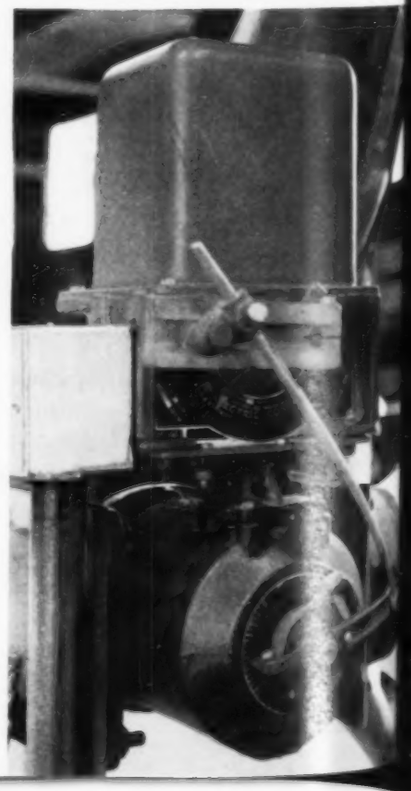
Twain this time — it will get worse before it gets better.

What is the answer? In one word, "improvisation". But that is a word which any bright schoolboy would put down. It's about as useful to the busy reader as "inventiveness", "resourcefulness" or "ingenuity" — all of which have already come to the reader's mind. Besides, the kind of improvisation going on is not so much a form of ingenuity as it is a fruit of knowledge of the science of instrumentation. In a larger sense it is not even improvisation but intelligent



has not heard of a single complaint by one of their purchasing agents. On the other hand he has overheard their engineers comparing notes with metallurgists (even metallurgists in plants producing defense materiel), the latter envying the former. On the whole, therefore, the supply of measuring, controlling and testing instruments has not been reduced. Quite the opposite; the total production of types and models available to both defense and non-defense industries is rising just about as fast as the total demand.

But — and here is the important qualification — a metallurgist cannot always obtain the particular piece of equipment he had set his heart upon. He has to shop around. He has to improvise. A few metallurgists are just awakening to this situation, which did not come about suddenly! But — to quote Grover Cleveland — it is a condition and not a theory, and — Mark



selection based on adequate knowledge of available methods, and correct application based on adequate knowledge of characteristics of procurable devices.

Which brings us to the most significant recent trend and suggests the nature of that portion which the Editor of METAL PROGRESS desires to be of "permanent reference value".

Metallurgists Are Co-Discoverers of Instrumentation

In February 1924 the word instrumentation, after long service in the domain of music, was adopted to denote a phase of modern technology. It has two newer meanings. The simpler meaning is physical; in this sense instrumentation means instruments — but not instruments in general, but a number of devices for measurement and automatic control intelligently and purposefully conceived, designed, developed, specified, installed and maintained. Thus the word means diversified apparatus whose duties are unified into a common function of measurement and control.

Note that even through this narrow physical definition — a definition of *things* — there shines forth the underlying idea of coordination; that is to say, of some kind of an art, or a craft, or a technique, or perhaps a science. It was with this underlying idea that the word instrumentation was endowed in 1924. The abstract meaning of instrumentation is therefore "the science of measurement and control".

The new science did not suddenly spring forth full-armed like Pallas Athene. No science does, or can. It naturally takes years to assemble and organize data, to formulate a body of doctrines and principles, to set them down in black and white, to get them published.

Metallurgists can share with chemical engineers the credit for discovering that a project had been under way since 1924 to formulate this new science. It was a metallurgist on the staff of the "Encyclopaedia Britannica" who arranged for the author to contribute to the 14th Edition (1929) an article on this new science and an editor of *Chemical and Metallurgical Engineering* who cooperated to print a special Instrumentation Issue. Likewise RICHARD RIMBACH, ⬢, undertook to publish the series of volumes on Measurement and Control and incorporated these very words in the title of the magazine he had founded in 1928.

Since then, ever-growing numbers of men in one industry after another have discovered the value of instrumentation — not merely the rather obvious advantages of using instruments instead of human senses, but the practical value of education and training in the science and technique of instrumentation. Today all progressive American technical journals make it their policy to publish articles on new equipment and on various phases of the science of instrumentation.

A cause-and-effect example, in which metallurgists shine, is afforded by the newest phase of instrumentation, namely automatic control of furnace atmospheres. Early in this century metallurgists saw the value of "neutral" or "protective" atmospheres, but they and the furnace builders lacked the concept of control. Furnace atmosphere was like the weather — a condition of importance but nobody could do anything about it. In 1915 a publication by WHITE and HOOD marked the first turning-point; suddenly we became aware that human brains *could* do something about it.

During the next 15 years metallurgists gradually defined what they wanted, but most of the solutions of the problems took the form of expensive equipment, high in first cost and requiring expert attention. Then in the mid-thirties, like a parachute flare suddenly lighting up the landscape, came the first application of that most essential instrumentation doctrine: *"Before a condition can be controlled it must be measured."* Metallurgists who had been indoctrinated, who had reaped rewards in the field of temperature control from their study of instrumentation principles, were the ones who taught the world, so to speak, that these same principles could be applied in obtaining "tailor-made" furnace atmospheres automatically. Having learned the fundamental lesson that all control problems are essentially similar, having learned the lesson of temperature control, they are "improvising" in a new field — they are writing and teaching the atmosphere control chapters for everybody's benefit — including erstwhile teachers turned students.

One "Secret" Is the Correct Choice of Elements in a System

Thus it is plain to see that the conquest of new fields consists largely in what roughly can be called improvisation, even when there are no shortages. In view of the increasing difficulty of obtaining certain complete automatic

Crystallography of the Chemical Elements

As Tabulated by William Hume-Rothery
in "The Structure of Metals and Alloys," Monograph No. 1, British Institute of Metals.

Emendations (by H.C. Vacher) represent values that have appeared in the literature from 1936 to 1940 inclusive.

Element Atomic No.	Electron Arrangement in Free Atoms	Crystal Structure (Note a)	Axial Ratio c÷a	Coordination No.	Lattice Constant a	Lattice Constant c	Interatomic Distance d_1	Interatomic Distance d_2	Atomic Diameter Coordination No. 12 (Note f)	Reference (g)
Group I A in Periodic Sequence										
3, Lithium	[2] 1	⧉	—	8	3.5019±2	—	3.033	—	3.13	13
11, Sodium	[2][8] 1	⧉	—	8	4.282 0±5	—	3.708	—	3.82	10
19, Potassium	[2][8][8] 1	⧉	—	8	5.333 5	—	4.618	—	4.76	—
37, Rubidium	[2][8][18][8] 1	⧉	—	8	5.62±0.03 at -173°C.	—	4.87 at -173°C.	—	5.02	—
55, Cesium	[2][8][18][18][8] 1	⧉	—	8	6.05±0.03 at -173°C.	—	5.24 at -173°C.	—	5.40	—
87, Virginium	[2][8][18][32][18][8] 1	—	—	—	—	—	—	—	—	—
Group I B										
29, Copper	[2][8][18] 1	⊡	—	12	3.607 8	—	2.551 1	—	2.551	—
47, Silver	[2][8][18][18] 1	⊡	—	12	4.077 8	—	2.883 5	—	2.883	—
79, Gold	[2][8][18][32][18] 1	⊡	—	12	4.069 9	—	2.877 8	—	2.877	—
Group II A in Periodic Sequence										
4, Beryllium	[2] 2	α=○	1.584 8	6,6	2.267 9	3.594 2	2.223 5	2.267 9	2.25	—
		β=○	1.52	—	2.1	10.8	—	—	—	1
12, Magnesium	[2][8] 2	○	1.623 6	6,6	3.202 2	5.199 1	3.190 0	3.202 2	3.20	—
20, Calcium	[2][8][8] 2	α=⊡	—	12	5.56	—	3.93	—	3.93	—
	at 300°C.	β=?	—	—	—	—	—	—	—	1
	at 460°C.	γ=○	1.64	6,6	3.94	6.46	3.94	3.955	3.98	—
38, Strontium	[2][8][18][8] 2	⊡	—	12	6.07 5	—	4.29 6	—	4.29 6	—
56, Barium	[2][8][18][18][8] 2	⧉	—	8	5.01 5	—	4.34 3	—	4.48	—
88, Radium	[2][8][18][32][18][8] 2	—	—	—	—	—	—	—	—	—
Group II B										
30, Zinc	[2][8][18] 2	○	1.856 0	6,6	2.659 0	4.935 1	2.659 0	2.906 1	2.748	—
48, Cadmium	[2][8][18][18] 2	○	1.885 9	6,6	2.973 1±2	5.606 9±5	2.973 1	3.287 2	3.042	1
80, Mercury	[2][8][18][32][18] 2	▱	α=70°31.7′	6	2.999 at -46°C.	—	2.999	—	3.10	—
Group III A in Periodic Sequence										
5, Boron	[2] 3	○	—	—	—	—	—	—	—	1
13, Aluminum	[2][8] 3	⊡	—	12	4.041 5±2	—	2.857 7	—	2.80 to 2.86 (note b)	3
21, Scandium	[2][8][9] 2	α=⊡	—	12	4.532	—	3.925	—	3.925	12
		β=○	1.585	6,6	3.30	5.23	3.23	3.30	3.265	12
39, Yttrium	[2][8][18][9] 2	○	1.588	6,6	3.663	5.814	3.595	3.663	3.629	—
57, Lanthanum	[2][8][18][18][9] 2	α=○	1.613	6,6	3.754	6.063	3.727	3.754	3.741	—
		β=⊡	—	12	5.296	—	3.745	—	3.745	—
89, Actinium	[2][8][18][32][18][9] 2	—	—	—	—	—	—	—	—	—
Group III B										
31, Gallium	[2][8][18] 3	▯	—	—	4.516 7	7.644 8 (note c)	—	—	—	—
		a÷b÷c = 1 : 0.998 68 : 1.692 57, b = 4.510 7								
49, Indium	[2][8][18][18] 3	△	1.07 8	4,8	4.585±4	4.941 1±5	4 at 3.24 2	8 at 3.37 0	3.13 8	1
81, Thallium	[2][8][18][32][18] 3	α=○	1.60 0	6,6	3.45 0	5.52 0	3.404	3.45 0	3.42 7	—
		β=⊡	—	12	4.84 1	—	3.42 3	—	3.42 3	—

Notes: (a) ⧉ is body-centered cubic; ⊡ is face-centered cubic; ○ is close packed hexagonal; ▱ is simple rhombohedral; ▯ is orthorhombic; △ is face-centered tetragonal

(b) Appears to be smaller in some alloys.

(c) 8 atoms to unit cell; each atom has 1 neighbor at 2.43 7, 2 at 2.70 6, 2 at 2.73 8 and 2 at 2.79 5.

(f) Atomic diameters for new values have been computed by following Hume-Rothery's procedure whenever possible.

(g) See Page 580, Metal Progress, May 1941.

control systems and even desirable components one of instrumentation's most valuable contributions to national defense at this time should take the form of a permanent reference-guide to the solution of problems through this kind of improvisation. It has already been defined as *(a)* intelligent selection, based on adequate knowledge of available methods and *(b)* correct application based on adequate knowledge of characteristics.

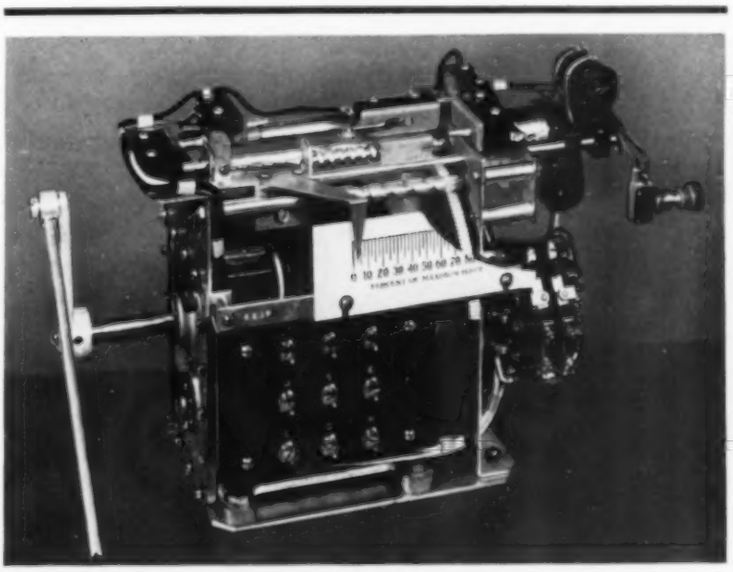
There is no space here for a complete reference-guide. This would amount to reprinting the "Manual of Instrumentation", the published chapters of which run to more than a thousand pages. Moreover, it is our intention to present new material which has to do with the field of intermediate elements.

Intermediate Elements

Intermediate elements have heretofore received little attention in comparison with the thorough analyses of the characteristics of primary measuring elements (such as thermocouples, gas conductivity cells, and so on) and of final control elements such as valves. Our treatment is applicable to *all* phases of metallurgical instrumentation — temperature, pressure, physical and chemical properties of metals, of furnace atmospheres and of individual gases — but in order to simplify it we shall assume that the only condition to be controlled is temperature. The reader can make a mental substitution with ease.

Perhaps a case study will serve better to illustrate how to use the following disclosure of prime-relay characteristics. A certain client decided to install a new temperature control system on a certain furnace and logically began his study with the required characteristics of the final element of the yet-unspecified control system. From the available data the conclusion emerged that the fuel and air valves should be of a definite type and of certain sizes; also that they should be operated hydraulically. Next came an investigation of primary elements responding to temperature and this logical second step in the study resulted in the choice of a closed-end refractory tube extending into the furnace, with a permanently installed, water-cooled radiation receiver sighting on its hot end. The third and final step was to select the intermediate elements of the system. Here is where the client ran into such complications and costs that the "logical" first and second steps apparently turned out to have been an illogical waste of time: On the one hand hydraulic operation of the valves required a relatively huge power input; on the other hand the "power output" of the pointer of an electrical instrument, actuated by the radiation received by the thermopile, was relatively feeble. Thus it appeared at this point that the radiation receiver should be hooked up to a control potentiometer commanding a pair of motor-driven valves, which in turn would command the hydraulic cylinders operating the fuel and air valves. The apparently inescapable conclusion was to abandon the idea of hydraulic operation, operate the fuel and air valves by reversing type of electric motors, and save money by having the control potentiometer command the fuel and air valve drives directly.

"Hold on! What makes you think that the thermopile cannot develop enough power to



The Lindberg "Throttling Control". Behind the terminal board is the valve-operating motor, connected by gear segment and long-pitch spiral to the pointer carriage which also carries contactors to stop the motor. Open position of valve is limited by contact with the roller on the limit switch at top of mechanism, adjustable in position through the second spiral and its reversible motor. When the high control point is reached, the adjustable limit switch is moved a little to the left, thus throttling the valve slightly when it next moves open

Crystallography of the Chemical Elements

As Tabulated by William Hume-Rothery
in "The Structure of Metals and Alloys," Monograph No. 1, British Institute of Metals.

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Group IV A in Periodic Sequence										
22, Titanium	[2][8][10] 2	α = ○	1.601	6,6	2.95₃	4.72₉	2.91₅	2.95₃	2.93	—
	(slightly over 900°C.)	β = ◻	—	8	3.32	—	2.87₅	—	2.96	2
40, Zirconium	[2][8][18][10] 2	α = ○	1.589	6,6	3.22₃	5.12₃	3.16₆	3.22₃	3.19	—
	(data for 867°C.)	β = ◻	—	8	3.61	—	3.12₆	—	—	—
72, Hafnium	[2][8][18][32][10] 2	○	1.587	6,6	3.20₀	5.07₇	3.13₉	3.20₀	3.17	—
90, Thorium	[2][8][18][32][18][10] 2	◻	—	12	5.07₇ or 5.09₁	—	3.59₀ or 3.60₀	—	—	—
Group IV B, Including Carbon and Silicon										
6, Carbon, diamond	[2] 4	◇	—	4	3.560₆	—	1.51₁₃	—	—	—
graphite		○ (b)	2.75	6	2.46	6.78	1.42	2.46	—	—
14, Silicon	[2][8] 4	◇	—	4	5.417₃±₅	—	2.345₇	—	—	1
32, Germanium	[2][8][18] 4	◇	—	4	5.64₇	—	2.44₅	—	2.78₈	—
50, Tin, gray	[2][8][18][18] 4	◇	—	4	6.46	—	—	—	3.164	—
white		△	0.545₆	4,2	5.819₄	3.175₃	3.016₁	3.175₃	—	—
82, Lead	[2][8][18][32][18] 4	◻	—	12	4.938₉	—	3.492₃	—	3.494	—
Group V A in Periodic Sequence										
23, Vanadium	[2][8][11] 2	◻	—	8	3.033₈	—	2.627₄	—	2.69	1
41, Columbium	[2][8][18][12] 1	◻	—	8	3.294±1	—	2.853	—	2.94	—
73, Tantalum	[2][8][18][32][11] 2	◻	—	8	3.295₉±₃	—	2.854₄	—	2.94	1
91, Protoactinium	[2][8][18][32][18][11] 2	—	—	—	—	—	—	—	—	—
Group V B										
7, Nitrogen	[2] 5	α = cubic	—	—	5.66	—	1.06	—	—	—
		β = hex.	1.63₃	—	4.03₄±₉	6.5₈₇±₁₅	—	—	—	1
15, Phosphorus, metallic	[2][8] 5	▯	a÷b÷c = 1 : 1.32 : 3.17		3.31	b=4.38	10.50	2.17	2.20	—
33, Arsenic	[2][8][18] 5	▱	α = 54°7.5′	3,3	4.13₅±₆	—	2.50₇	3.13₉	—	1
51, Antimony	[2][8][18][18] 5	▱	α = 57°6.5′	3,3	4.497₆±₂	—	2.879₅	3.378₄	3.228	1
83, Bismuth	[2][8][18][32][18] 5	▱	α = 57°14.2′	3,3	4.735₆±₆	—	3.103₆	3.472₈	3.64	1
Group VI A in Periodic Sequence										
24, Chromium	[2][8][13] 1	α = ◻	—	8	2.878₆	—	2.492₉	—	2.57	—
		β = ○	1.626	6,6	2.71₇	4.41₈	2.709	2.717	2.71	—
42, Molybdenum	[2][8][18][13] 1	◻	—	8	3.140₃	—	2.719₆	—	2.80	—
74, Tungsten	[2][8][18][32][12] 2	α = ◻	—	8	3.158₃	—	2.735₂	—	2.82	—
		β = cubic (c)	8 atoms in unit cell		5.038	—	2.519	2.816	—	—
92, Uranium	[2][8][18][32][13][12] 2	▯	4 atoms in unit cell		2.852	4.945	2.76	2.85	—	9
			a:b:c = 1:2.056:1.734,			b=5.865				
Group VI B										
8, Oxygen	[2] 6	α = ▯	4 atoms in unit cell		5.50	3.44	—	—	—	1
			a:b:c = 1:0.691:0.625,			b=3.82				
		β = ▱	α = 99.1°; 12 atoms in unit cell		6.19	—	—	—	—	1
		γ = cube	16 atoms in unit cell		6.83	—	—	—	—	1
16, Sulphur	[2][8] 6	α = ▯	128 atoms in unit cell		10.48	24.55	2.12	3.36	—	1
			a:b:c = 1 : 1.233 : 2.343,			b=12.92				
at 103°C.		(d) mono-	a:b:c = 1:1.011:1.006		10.90	10.96	—	—	—	7
		clinic	β = 83°16′;			b=11.02				
34, Selenium	[2][8][18] 6	○ (e)	1.140	2,4	4.337	4.945	2.316	3.457	—	—
		monoclinic (α)	a:b:c = 1:0.998:1.281		8.992	11.52	—	—	—	1
		32 atoms in unit cell; β = 91°34′;				b=8.973				
		monoclinic (β)	a:b:c = 1:6.311:7.261		12.74	9.25	—	—	—	1
		32 atoms in unit cell; β = 93°4′;				b=8.04				
52, Tellurium	[2][8][18][18] 6	○ (e)	1.33	2,4	4.445	5.912	2.858	3.46	—	—
84, Polonium	[2][8][18][32][18] 6	pseudo hexagonal	3 atoms in pseudo cell		4.25	7.06 or 14.12	—	—	—	6
		probably monoclinic;	a:b:c = 1:0.578:1.900		7.42	14.10	3.4	4.0	—	6
		12 atoms in unit cell; β = 92°;				b=4.29				

Notes: (a) ◻ is body-centered cubic; ▱ is face-centered cubic; ○ is close packed hexagonal except as noted; ◇ is diamond; △ is tetragonal; ▱ is rhombohedral, and ▯ is orthorhombic.

(b) Graphite is hexagonal, not close packed, with four atoms per unit cell.

(c) Cubic structure; two positions distinguishable, X and Y. Each atom X has 12 Y at 2.816 Å; each atom Y has 2 Y at 2.519 and 4 X at 2.81[illegible] Å.

(d) Unit cell contains 48 S or 6 S_8.

(e) Hexagonal, not close packed; each atom has 2 neighbors at d_1 and 4 at d_2.

(f) Atomic diameters for new values have been computed by following Hume-Rothery's procedure whenever possible.

(g) See Page 580, Metal Progress, May 1941.

actuate a hydraulic relay?" the client was asked.

"I don't think it; I know it. Everybody knows how delicate a millivoltmeter is. All we can get from a thermopile is millivolts — certainly not volts — and with milliamperes as the maximum current, we only have microwatts for deflecting a pointer. How can such a pointer actuate even the most exquisitely balanced pilot oil valve without the drag causing serious errors? How can it actuate *two* pilot oil valves?"

The trouble was that the client thought only in terms of the conventional d'Arsonval type of millivoltmeter. There are solenoid and other types which are commonly used as control elements in various electrical engineering applications. But the client did not even have to shop around in the unfamiliar field of automatic millivolt regulators. He was shown a drawing of a combination millivoltmeter and hydraulic relay which came out in Europe some ten years ago and there was a happy ending to this story in the discovery that such a combination was on the American market.

Characteristics of Prime Relays

One of the ways of classifying all industrial temperature instruments is:

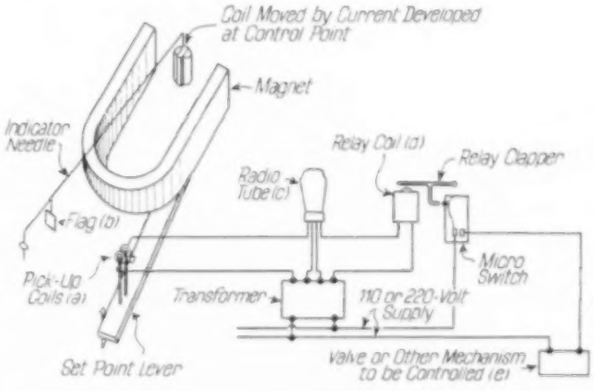
1. Direct acting, or direct writing, or direct deflection, or self operating equipments, and

2. All others; which employ an external source of power.

The latter are called "relay" or "servomotor" instruments, both exact designations, because a device or system of this kind makes use of a relatively powerful servant and commands this servant by means of some arrangements which we may call a pilot or relay. We are concerned here with the most important — the prime or initial relay, the one immediately associated with the measuring element. In any control system of this second class, the primary measuring element is the most important member of the team; and the prime relay is the one to study with greatest care. To study these numerous kinds of relays we must classify them. Throughout the following discussion, the word relay is used to denote the means whereby the measuring element is enabled to command a servo mechanism without doing any other work than actuate the relay.

1. *Pneumatic Prime Relays* — This class is mostly made up of compressed air devices but it includes vacuum systems and gas operated systems. The characteristic feature of the usual dead-end and bleed arrangement is a single line for controlled air leading from pilot to power device, so that the action is uni-directional ("single action"). In the usual power device a flexible diaphragm is moved in one direction by the air pressure and in the other by a spring. The characteristic "give" prevents locking-in-place of the power device and, if the controlled valve is imperfectly balanced, load error ("droop") is inevitable. However, there have appeared secondary pneumatic relay systems known as "regulators" or "valve positioners" which provide micrometric lock-in when properly adjusted. Some are double-action systems comparable to the hydraulic class.

So-Called "Radio Principle" Utilized in Wheelco Instruments Since 1933. Current from the thermocouple swings pointer toward right, and the inductance of coils (a) is varied as flag (b) passes between. This changes input to radio tube (c), and its corresponding output. The latter operates relay (d) which controls required mechanism (e)



Most primary pilots, directly actuated by the measuring elements, impose practically no variable drag on the measuring elements; and some of the fully balanced and floating designs are entirely free from metal-to-metal friction.

Pneumatic relay instrumentation is relatively inexpensive, except where large high-pressure valves must be commanded, in which case the lower cost of electric motor-driven valves may offset the differences in all the other elements of the systems. Compressed air storage tanks assure continuous operation if electric power is interrupted. (Intelligence officers, take notice!) Speed of operation of power device is also readily adjustable.

Crystallography of the Chemical Elements

As Tabulated by William Hume-Rothery
in "The Structure of Metals and Alloys," Monograph No. 1, British Institute of Metals.

Emendations (by H.C. Vacher) represent values that have appeared in the literature from 1936 to 1940 inclusive.

Element Atomic No.	Electron Arrangement in Free Atoms	Crystal Structure (Note a)	Axial Ratio c÷a	Coordination No.	Lattice Constant a	Lattice Constant c	Interatomic Distance d_1	Interatomic Distance d_2	Atomic Diameter Coordination No. 12 (Note f)	Reference (g)
Group VII A in Periodic Sequence										
25, Manganese	[2][8][13] 2	α = cubic (note b)		—	8.894	—	—	—	—	—
		β = cubic (note c)		12	6.300	—	—	—	—	—
		γ = △	0.934	—	3.774	3.526	2.582	2.669	—	—
43, Masurium	[2][8][18][14] 1	—	—	—	—	—	—	—	—	—
75, Rhenium	[2][8][18][32][18] 2	○	1.6148	—	2.7553	4.4493	2.7349	2.7553	2.75	—
Group VII B										
9, Fluorine	[2]7	—	—	—	—	—	—	—	—	—
17, Chlorine	[2][8]7	△	0.715	—	8.56	6.12	1.88 (note e)	—	—	4
		16 atoms in unit cell								
35, Bromine	[2][8][18]7	□	a:b:c = 1:1.49:1.95		4.48	8.72	2.27	noted	—	5
		8 atoms in unit cell; b = 6.67								
53, Iodine	[2][8][18][18]7	□	a:b:c = 1:1.51:2.04		4.795	9.780	2.70	noted	—	—
		8 atoms in unit cell; b = 7.255								
85, Alabamine	[2][8][18][32][18]7	—	—	—	—	—	—	—	—	—
Group VIII in Periodic Sequence										
26, Iron	[2][8][14] 2	α = ◎	—	—	2.861	—	2.477	—	—	—
		β = □	—	—	3.64 at 900°C.	—	2.580	—	2.52	—
27, Cobalt	[2][8][15] 2	α = ○	1.624	—	2.507	4.072	2.499	2.507	2.50	—
		β = □	—	—	3.545	—	2.507	—	2.507	—
28, Nickel	[2][8][16] 2	α = ○	1.64	—	2.49	4.08	2.49	2.49	2.49	—
		β = □	—	—	3.517o	—	2.4869	—	2.487	—
44, Ruthenium	[2][8][18][15] 1	○	1.583	—	2.6984	4.273o	2.644	2.698	2.67	8
45, Rhodium	[2][8][18][16] 1	□	—	—	3.795s	—	2.6838	—	2.684	—
46, Palladium	[2][8][18][18]	□	—	—	3.8824	—	2.7453	—	2.745	—
76, Osmium	[2][8][18][32][14]2	○	1.579	—	2.7298	4.3104	2.670	2.730	2.70	8
77, Iridium	[2][8][18][32][15]2	□	—	—	3.831z	—	2.7091	—	2.709	—
78, Platinum	[2][8][18][32][16]2	□	—	—	3.915a	—	2.7689	—	2.769	—
Rare Earth Group										
58, Cerium	[2][8][18][19][9]2	α = ○	1.62	6,6	3.65	5.91	3.63	3.65	3.64	—
		β = □	—	12	5.143	—	3.637	—	3.637	—
59, Praseodymium	[2][8][18][20][9]2	○	1.620	6,6	3.657	5.924	3.638	3.657	3.65	—
60, Neodymium	[2][8][18][21][9]2	○	1.608	6,6	3.657	5.88	3.619	3.657	3.64	—
67, Holmium	[2][8][18][28][9]2	○	1.580	6,6	3.557±3	5.620±5	3.480	3.557	3.52	11
68, Erbium	[2][8][18][29][9]2	○	1.63	6,6	3.74	6.09	3.73	3.74	3.73	—

Notes: (a) ◎ is body-centered cubic; □ is face-centered cubic; ○ is close packed hexagonal; □ is orthorhombic; △ is tetragonal.

(b) Approximates ◎ where each lattice point is a cluster of 29 atoms; 1 type X, 4 type A, 12 type D_2 and 12 type D_1. The X atoms occupy the largest volume and the D_2 the smallest. Interatomic distances of neighboring atoms are as follows:

X atoms have: 12 D_2 at 2.71; 4 A at 2.82

A atoms have: 1 X at 2.82; 3 D_1 at 2.49 and 3 at 2.96; 3 D_2 at 2.69 and 3 at 2.89

D_2 atoms have: 1 X at 2.71; 2 A at 2.69 and 1 at 2.89; 1 D_2 at 2.24 and 2 at 2.38; 1 D_1 at 2.45, 2 at 2.51 and 2 at 2.66

D_1 atoms have: 1 A at 2.49 and 1 at 2.96; 1 D_2 at 2.45, 2 at 2.51 and 2 at 2.66; 6 D_1 at 2.67

(c) Complicated structure with 20 atoms of two kinds in unit cell. Each atom of the first kind has:

3 neighbors at 2.365
3 " " 2.530
3 " " 2.671
3 " " 2.675

Each atom of the second kind has: 2 neighbors at 2.530
2 " " 2.615
4 " " 2.659
2 " " 2.671
2 " " 2.675

(d) Atoms arranged in pairs so that each one has one close neighbor at a distance d_1.

(e) The authors give 1.99 as the closest approach to a neighboring atom, however, they did not indicate clearly the space group. If the space group is D_{4h}^{16} with 16 atoms to a unit cell and the X, Y, and Z parameters are 0.125, 0.167 and 0.107, respectively, then $d_1 = 1.88$.

(f) Atomic diameters for new values have been computed by following Hume-Rothery's procedure whenever possible.

(g) See Page 580, Metal Progress, May 1941.

Recent developments in pneumatic circuits comprising a succession of relays (similar to the principle of "cascading" and "feed-back" with electron tubes) have added stability and have thus made the pneumatic system capable at last of meeting difficult variable loads. (However, it may be worth mentioning that the modern pneumatic relays were invented and developed by instrument men for instrument men.)

2. *Hydraulic Prime Relays* — Although the Greek root means "water", this class comprises all systems where an "incompressible" fluid is the operating medium. In control systems, oil is most frequently used. Ample power of cylinders, positive operation, and possibility of locking-in-place are the most obvious characteristics. In general the action is relatively slow, but accurate adjustment of speed is an advantage. On the other hand, jerky action is all too frequent in some cheap systems.

Most pilot valves with longitudinal motion consume too much energy for actuation by electrical movements and by most other measuring elements. This undesirable erratic drag effect has been minimized in the newer pilots and almost eliminated in the pivoted "jet-pipe" relay. Prodigious ingenuity is evident in recently perfected hydraulic circuits, mostly inspired by those of turbo-generator governors.

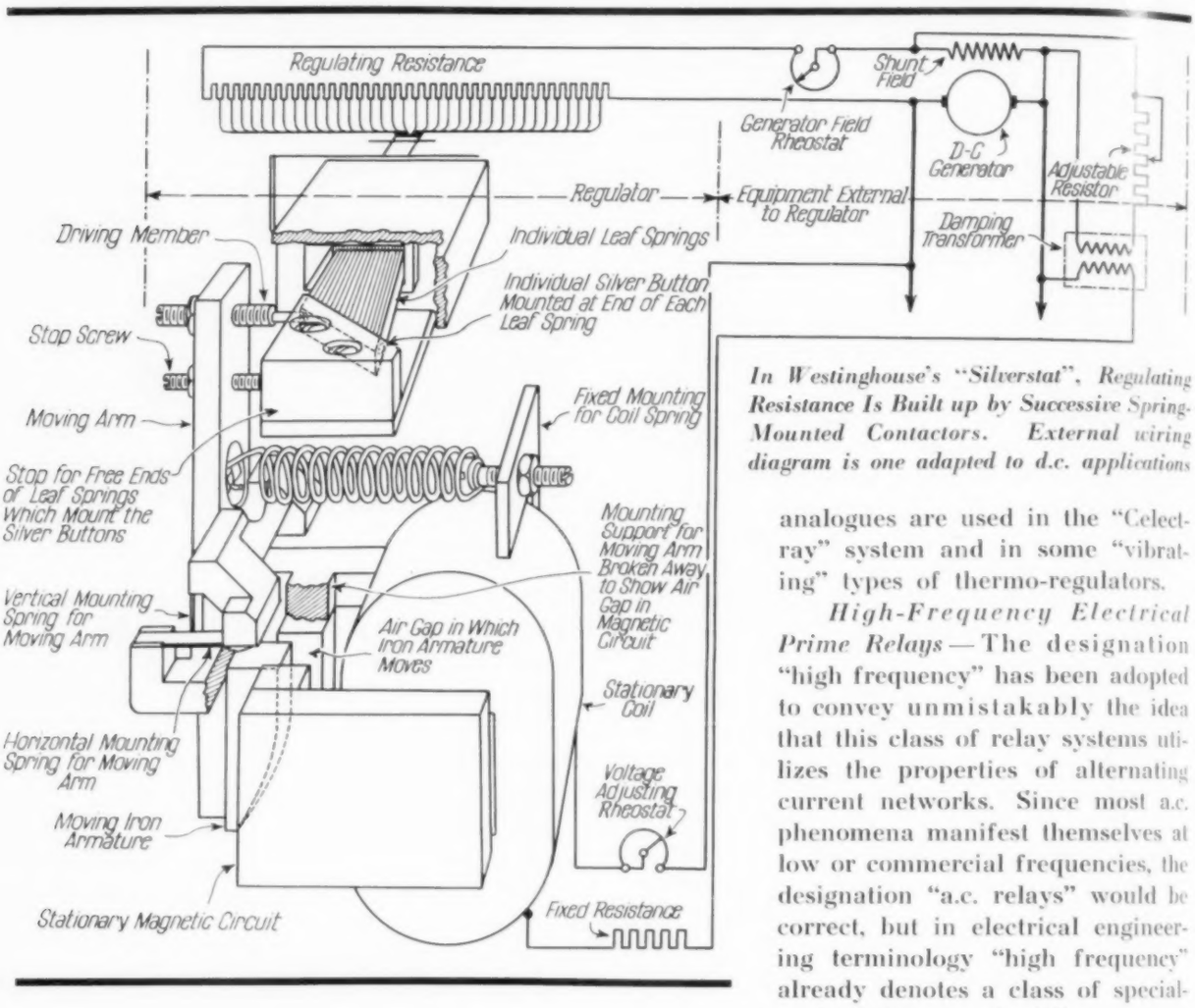
3. *Mechanical Prime Relays* — It is mostly in the recording, integrating and totalizing instruments that one finds mechanical relay and amplification systems. The enormous disproportion between the classes and types of escapements, clutches, triggers, torque amplifiers, and other mechanisms, and the total number in use precludes further discussion here, except to invite attention to the fact that the proper performance of many recording and controlling instruments employing mercury switches, electric contacts or electric-driven charts depends upon the correct functioning of mechanical relays actuated by feeble measuring elements and, in turn, operating the electrical devices.

4. *Electrical Prime Relays* — The great majority of electromagnetic relay systems in industrial instrumentation are "on-and-off" devices whereby circuits are instantaneously opened or closed. The simplest are those wherein contacts are directly attached to the pointers. These are electric rather than electromagnetic and they naturally divide themselves into single-contact, high-low, and so-called "three-position". Next come the true electromagnetic relay arrangements, whereby relatively delicate contacts at the pointer actuate a power relay with relatively high ratings. ("Power relay" here denotes a great variety of switchgear, all described in readily accessible handbooks of electrical engineering.)

"Converter" Used in Latest Brown Instruments. In this any small direct current from a control point is transformed into an alternating voltage, and amplified sufficiently to operate a motor to which is directly geared the indicator, recorder, and slide wire contactor on the null-balance measuring circuit

The two principal classes of power devices commanded by the measuring element through electric and magnetic relays are solenoids and motors. In general, solenoids provide practically instantaneous action and motors permit a choice of speeds.

Although most electromagnetic relays are of the on-and-off type, there are several others which provide "throttling" modes of control — some step-by-step, others continuously variable. The simplest arrangement is to have the instrument pointer wipe a rheostat, but this imposes a drag on the measuring system and as a rule can only command another instrument of the pointer type. A modification is to have the pointer wipe a voltage-dividing resistor (commonly and erroneously called a potentiometer) which in turn positions a solenoid-and-contactor balancing arrangement commanding a relatively large motor. Another modification is the Allis-Chalmers rocking-contact type of resistor which is so frictionless that a damping device to prevent overshooting is a standard part of this "pilot". Another step-less


Regulating Resistance
Shunt Field
Generator Field Rheostat
D-C Generator
Adjustable Resistor
Regulator
Equipment External to Regulator
Damping Transformer
Driving Member
Individual Leaf Springs
Individual Silver Button Mounted at End of Each Leaf Spring
Stop Screw
Moving Arm
Fixed Mounting for Coil Spring
Stop for Free Ends of Leaf Springs Which Mount the Silver Buttons
Mounting Support for Moving Arm Broken Away to Show Air Gap in Magnetic Circuit
Vertical Mounting Spring for Moving Arm
Air Gap in Which Iron Armature Moves
Stationary Coil
Horizontal Mounting Spring for Moving Arm
Voltage Adjusting Rheostat
Moving Iron Armature
Stationary Magnetic Circuit
Fixed Resistance

In Westinghouse's "Silverstat", Regulating Resistance Is Built up by Successive Spring-Mounted Contactors. External wiring diagram is one adapted to d.c. applications

arrangement is found in the Westinghouse "Silverstat". Other continuously-variable electrical relay systems have been devised.

The effect of a continuous variation or "throttling" is obtained by vibrators and other circuit-interrupting devices (some of which are combination mechanical and electrical relays) whereby the closed-circuit time in each cycle of operation is a function of the position of the pointer. The resulting mode of control is applicable only to processes with adequate energy storage or "flywheel effect". Therefore this equivalent of throttling is chiefly used for the control of electric heat. Modern inverse-time relays of high rating for such heavy duty as furnace temperature control have periods of one to five minutes. Other temperature controllers have periods down to a few milliseconds. The original inverse-time cyclical interrupting device, invented by Gouy in 1897, held the temperature of a bath steady to within 0.005° C., but was of relatively low wattage. Its modern analogues are used in the "Celectray" system and in some "vibrating" types of thermo-regulators.

High-Frequency Electrical Prime Relays — The designation "high frequency" has been adopted to convey unmistakably the idea that this class of relay systems utilizes the properties of alternating current networks. Since most a.c. phenomena manifest themselves at low or commercial frequencies, the designation "a.c. relays" would be correct, but in electrical engineering terminology "high frequency" already denotes a class of specialized devices much different from the systems here considered.

The outstanding characteristic of high frequency a.c. relays is the possibility of eliminating drag by doing away with contacts and pilot valves. In some systems the pointer or equivalent element serves as one plate of a variable capacitor, in others it serves as the control element in an inductive coupling, the mechanical reaction in either case being almost negligible.

Aside from these pointer-displacement systems there are others in which the relay is actuated without any mechanical motion at all. These latter, of course, can only be used in conjunction with static measuring systems in which the measured temperature is translated into an exactly proportional electrical magnitude. This representative electrical magnitude need not itself be an alternating current effect; the feeble direct current from a thermocouple, for example, can be used as the controlling input.

Relay systems of this class are erroneously

called "electronic" in nearly all booklets describing the recorders, controllers and telemetering system in which they are used. This is incorrect even when electron tubes are used incidentally.

Among the most sensitive systems of this class are resonant networks adapted from radio and employing electron tubes as "servants" of the prime relay. The earliest ones for industrial temperature control known to the writer were developed by Wheelco Instruments Co. in 1933, and employed tuning phenomena and radio tubes. But while they may all be said to use a "radio principle", they should not really be classified as electronic relay types.

5. *Electronic Prime Relays* — In this newest class of control devices the relay proper is an electron tube, directly actuated by or fed from the measuring element or system. Although relatively few of the hundreds of commercial types of electron tubes are suitable as *prime* relays, other types are employed in the numerous circuits which have been developed to take full advantage of the general characteristics of electronic relays.

First among these general characteristics is suitability for actuation by static measuring elements (no moving parts). Conversely, no ordinary pointer-and-scale type of measuring element can be equipped with an electronic relay; and no ordinary type of electron tube can serve as a relay in conjunction with a measuring element of the mechanical displacement type.*

The second outstanding characteristic is the enormous amplification of electronic relays — up to 1500× in each stage. The third general characteristic is rapidity — instantaneous action. Other general characteristics (to which there are exceptions) are: Limited life, gradual or sudden alteration of tube constants without outward sign, fragility, low cost of spares, ease of replacement, and relative instability where the signal from the measuring element is of the order of a few millivolts of direct current.

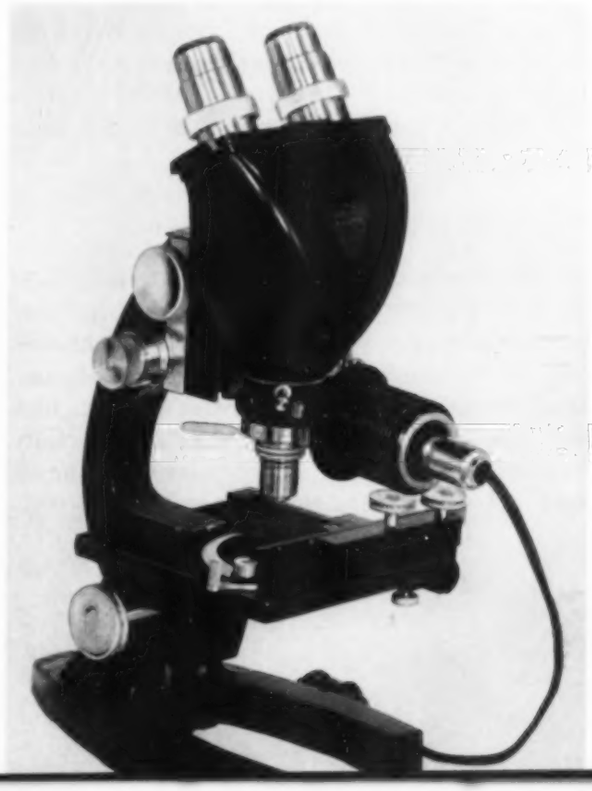
Electron tubes differ from all other relays in that while the constants of a tube are mostly inherent and are intended to be unaffected by external factors, their operating characteristics depend on external factors such as ambient temperature, character of signal, whether the load is purely resistive, inductive, capacitive or a combination thereof.

Inherent electron tube characteristics depend on inter-related features of design and construction. With regard to the character of the space there is a twofold division: *(a)* Vacuum tubes, being evacuated down to a pressure of a millimicron or less, and *(b)* gas-filled or vapor-filled tubes, evacuated then filled with a pure gas or vapor at pressures between 5 and 500 microns. With regard to types of cathodes there are *(a)* thermionic, *(b)* photo-electric, *(c)* cold and *(d)* pool, only the first two being commonly used in measurement work and only the thermionic tubes being suitable for service as prime relays directly actuated by any measuring elements having electrical outputs.

With regard to structure, the tri-odes and screen-grid tubes are the ones chiefly used. With regard to control of the electron stream there are *(a)* electrostatic means such as grids or plates, *(b)* electromagnetic means, generally coils outside the glass envelope, and *(c)* combination tubes. All of these are suitable in principle, so that practical considerations of dimensions, weight, cost and availability have caused the electrostatic-control tubes to be adopted most widely.

As to the nature of the envelope there are *(a)* glass and *(b)* metal tubes, the characteristics being fragility and availability — metal tubes still being relatively scarce.

Bausch & Lomb's Binocular Metallographic Microscope of Brand New Design



*Phototubes are *not* electronic relays. Even in a photo-electric, optical pyrometric system where "brightness temperature" is measured and controlled, the phototube cannot be the relay because it is the measuring element. The same is true of a mercury vapor, grid controlled rectifier when used as the temperature-responsive element in a thermostat.

Summing up, we may say that the single type most suitable for relay service as understood here may be described as follows: High vacuum, thermionic-emission or heated cathode, amplifier tube with one or more electrostatic control electrodes.

So numerous are the built-in means of control and the external methods of control ("hook-ups") that further discussion cannot be attempted.

6. *Photo-Electric Prime Relays* — This class of relays comprises both phototubes and photocells. Outside the field of instrumentation the former are considered "electron tubes" and in nearly all texts they are lumped together with the electronic relays mentioned above, while photocells are excluded. For our purpose the only criterion is that electronic relays respond to purely electrical effects and have purely electrical outputs; whereas photo-electric relays are all those which respond to light and have electrical outputs.

There are three classes of such devices ("selenium" or photo-resistive, photo-emissive, and photo-voltaic). All are widely used as measuring elements, but this is not the function considered here. Their chief characteristics when used as relays are *(a)* absence of drag on the measuring element, and *(b)* practically instantaneous response — the lag of the "selenium" and photo-voltaic classes being negligible.

Other characteristics differ widely with the classes and types. There is no such thing as a phototube or photocell with perfectly and permanently linear relationship between electrical output and intensity of illumination; all suffer to some extent from fatigue or temperature coefficient, but these effects are not noticeable when the tube or cell is applied as a simple trigger relay. Therefore, in applications requiring proportionality, they are preferably used in matched pairs and the deflection of the measuring element determines the ratio of the light falling on each.

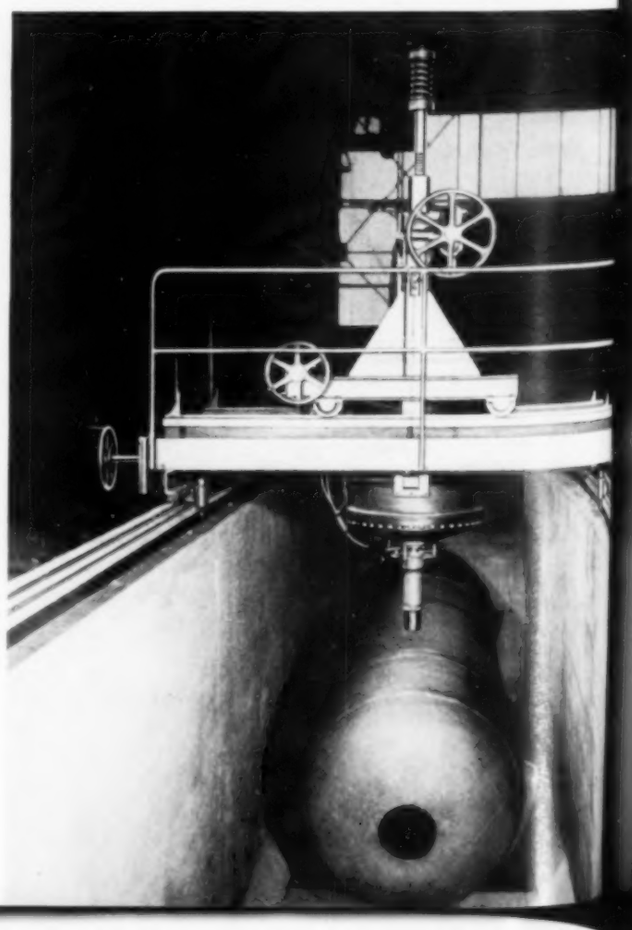
Study the Time Elements

The ingenuity being increasingly displayed by metallurgist-instrumenticians in their improvisations depends largely on their knowledge of the characteristics of their equipments. The foregoing analysis reveals in particular that *time* of reaction or response is especially important. Nowhere is this more significant than in temperature and atmosphere control. Moreover, in these metallurgical fields of automatic control, the most troublesome delays and lags characterize neither the control instruments proper nor the valves commanded by these instruments but the primary elements themselves. Even more specifically, the most serious lags are not inherent in the types of primary measuring elements but in their actual forms. Thus a thermocouple with a fine gage wire may have a lag coefficient of half a second but it may be protected by such an ill-chosen set of ceramic tubes that the whole assembly lags half an hour! Again, a particular type of gas-analysis cell may have an intrinsic lag coefficient of 0.2 sec. but its sampling tube may introduce a *delay* (not an exponential function but a plain delay) of several minutes.

No controller can be better than its primary measuring element! Therefore, the proper performance of a controller depends, as does that of a manager, on the correctness and timeliness of the information it receives. It depends also on the limits of time, space and force within which its power may be exercised. Consequently, we lay down these basic requirements for automatic control of processing conditions in furnaces and other metallurgical apparatus:

1. The condition to be controlled — or its variation — must be measurable.

1,000,000-Volt X-Ray Machine and Carriage Made by General Electric X-Ray Corp. and Installed by Babcock & Wilcox For Radiographing Joints in Steel up to 8-In. Thick



Exposure Chart for Radiography of Steel

By Herbert R. Isenburger

St. John X-Ray Service, Inc., Long Island City, N. Y.

THESE DIAGRAMS are based on the following combination: Pulsating direct current tension generating equipment; line focus, grid action X-ray tube; high speed industrial intensifying screens; blue base safety film; 5 min. development at 65° F.; film density 0.7.

A solution is shown of this problem: "Find the correct exposure on 17-in. film at 36-in. focus-film distance for 3-in. boiler plate of density 7.85 using 220,000 volts and 8 milliamperes."

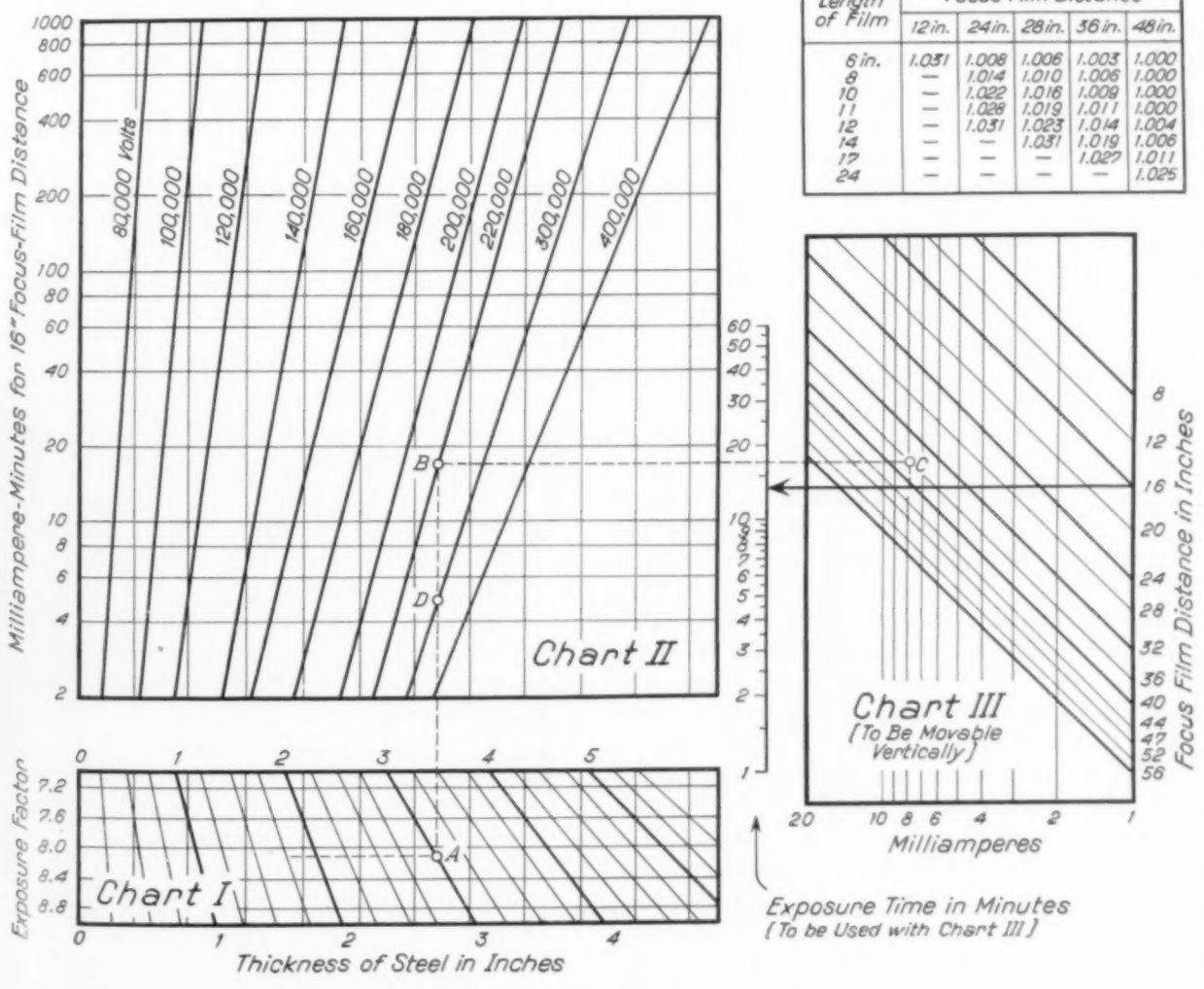
To compute the exposure factor at the ends of films of various lengths and at different focus-film distances, the factors shown in the table are multiplied by the actual density of the steel. In this example the factor 1.027 is located in the column for 36-in. focus-film in the line for 17-in. film. Multiply 1.027 by 7.85, the density of the steel to be radiographed, and the exposure factor is 8.1.

Find intersection of 8.1 with 3-in. line on Chart I (Point A), project upward to voltage of tube (Point B on 220,000-volt line in Chart II). Adjust Chart III so that Point C (corresponding to 36-in. focus-film distance and 8 milliamperes) is opposite Point B, and exposure time is read on central scale against arrow: 13½ min.

Scattered radiation must be filtered to get sharp definition above 250,000 volts, and the use of such filters requires increased exposure times as follows: 10% for 1½ to 2 in. of steel, 20% for 2 to 3 in., 40% for 3 to 4 in., and 50% above 4 in. For instance, suppose the conditions in the above problem remain the same, except a 300,000-volt source is to be used. Adjust Point C opposite Point D and exposure time is found to be 3½ min. without filter, which, increased 20%, comes to 4.2 min.

Table of Exposure Factors

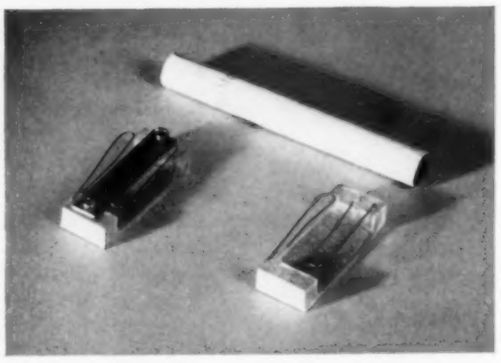
Length of Film	Focus Film Distance				
	12 in.	24 in.	28 in.	36 in.	48 in.
6 in.	1.031	1.008	1.006	1.003	1.000
8	—	1.014	1.010	1.006	1.000
10	—	1.022	1.016	1.009	1.000
11	—	1.028	1.019	1.011	1.000
12	—	1.031	1.023	1.014	1.004
14	—	—	1.031	1.019	1.006
17	—	—	—	1.027	1.011
24	—	—	—	—	1.025



2. The primary element of the controller must be suitable for the measurement and be properly installed.

3. The power device commanded by the control must be adequate.

4. The measuring means must command the corrective means without having its own properties impaired.



Tiny Strain Gages Sensitive to 15 Psi. in Static Tests Yet Usable at Frequencies of 30,000 Cycles per Second. (*Courtesy Baldwin Southwark*)

Ordinary self-operating controllers cannot strictly meet the fourth requirement, but the effort exerted by their measuring-and-operating elements is minimized, for example, by the use of balanced valves, and their applications still outnumber all relay control systems together. The most important applications in process control, however, require relays, some with elaborate amplifying systems, whereby the moving element of the measuring system is free from mechanical drag or electrical effects.

An obvious solution of the drag problem is exemplified in those controllers (both self-operating and relay) in which the measuring system has no moving parts at all. This leads to the following classification:

Class I. KINETIC OR DYNAMIC: ... All measuring systems in which variations in the controlled condition are represented by mechanical displacements.

Class II. STATIC: ... Saturable magnetic circuits. Electronic devices. Circuits utilizing nonlinear resistances.

Another solution eliminates moving parts from the power unit (as by using electronic devices). It is exemplified in various controllers for electrically heated apparatus.

In no case can a controller react to a deviation smaller in value than the value of its sensitiveness. But this does not mean that a controller, effectively sensitive to a given amount of change in the controlled condition, will necessarily be capable of *controlling* this condition within the limits of departure equal to the value of such sensitiveness. In most cases the reason is that the entire installation, looked at as a unit, does not meet all of the four requirements stated above. Even when these requirements are satisfactorily met, the record of the controlled condition may show peaks and valleys several times greater than the total deviation which causes effective action at the point of control.

When we analyze such installations we always find the causes of unsatisfactory control to involve time elements — lags and delays. There never is any exception.

One obvious reason why perfect control is unattainable is that the primary element of an actual controller cannot measure a variable with ideal accuracy. The "point" is the ideal, the "zone" is the actuality. But another reason is that the "instant" is the ideal and the "interval" or "period" is the actuality. No controller instantaneously detects and measures a deviation from a setting "point", or a departure from a definite zone of normality.

In automatic control, time factors usually are foes; seldom are they friends. However, let it be said that the obviously desirable kind of instrumental lag known as "measuring-element damping" is not under discussion.

The commonest form of the time characteristic of a measuring element is the logarithmic decrement curve or the asymptotic approach. It is closely approximated in many temperature measuring elements and in the continuously responsive types of gas analysis cells (the intermittent types introduce a plain delay).

In many cases the curve exhibits what may be termed the "delayed start effect". This is an inevitable result of extra-heavy protecting tubes, or overly capacious sampling devices.

Canny metallurgists are learning that there is a mathematically predictable relation between slowness and sensitivity. Space does not permit a demonstration, but the conclusion has been put in the form of a slogan: "Dead times mean dead zones".

Worse yet, an ideally sensitive control *instrument* is an undesirable one to use with an excessively protected thermocouple or with a slow gas-analysis cell because overshooting will be inevitable. This effect has been denied by some theorists when analyzing the performance of their pet controllers. The reason is not

apparent at first glance. But it is true — demonstrably true in the plant as well as on paper. It follows from the truism that "the controller is always controlling what the variable *was*, not what it *is*".

Trends in Testing

Some of the outstanding trends in the various fields of testing — testing of materials and finished products — have been so competently interpreted in this section of the last four or five October issues, as well as in other issues of METAL PROGRESS, that we must refrain from re-travelling well-beaten paths. One trend, as yet unheralded, begins to be noticeable, however. It may be called the "instrumentizing of testing machines".

This trend has two phases. The first began to attract attention some ten years ago, when tensile testing machines were first equipped with "dragless" autographic systems inspired by the prime-relay devices and servo-motors of industrial recorders and controllers. The second phase — just appearing — is the complete re-design of old machines, as well as the design from scratch of machines for new tests, in accordance with the well-tried principles of industrial indicating and recording instruments rather than along traditional lines.

Gone are polished brass pillars, exquisitely hand-drawn and hand-engraved dials; gone are the mahogany bases. Back of this visible trend we may discern a growing appreciation of the doctrine usually expressed as "*isolate* each variable and measure it in order to control it". There evidently is a growing determination to make each testing machine isolate one *property* and measure it and it alone, by controlling every factor and condition bearing upon the variations of this single property.

A third phase of today's trends might be termed "automatization" — a word that requires some practice to pronounce — not in the sense of adding an automatic control instrument to the testing machine but in converting the machine for use on the quantity production line and making it suitable for operation by semi-skilled employees. This phase or trend, of course, is not recent.

In the light of these three phases (chiefly the second) we may venture to mention a few examples which came to memory or which were merely stumbled upon in browsing through a pile of technical journals (a random pile, not a carefully indexed file).

The articles by GORDON WILLIAMS in METAL PROGRESS during the last few months constitute such a competent correlation of testing topics, including impact (or notched bar test) and the various types of hardnesses, that our plain duty is merely to remind the reader to consult these articles if he has so far neglected them.

Autographic records are nothing new in tensile testing machines, but we may mention what appears to be their first introduction in the testing of the finest radio tube wires and other filamentary specimens. G. C. STAUFFER described in the June 1939 *Metals and Alloys* such an ultra-sensitive autographic tester. Extensometers made of fine wires cemented to the metal under test are widely used for studying the stresses in aircraft members during flight. Variations in length mean variations in cross section and electrical conductivity, and these can be measured and recorded by oscillographs and similar devices.

A new type of pulsating tension-fatigue machine for small-diameter wire was described by JOHN N. KENYON of Columbia University before the A.S.T.M.'s annual meeting in 1940, and well received by distinguished authorities. It employs three reciprocating forces in 120° phase relation, exerting a constant driving torque and thereby eliminating unbalanced inertia effects. (By the way, the last six or seven annual volumes of the A.S.T.M. *Proceed-*

Latest Model of "Rockwell" Motorized Hardness Tester. (Courtesy Wilson Mechanical Instrument Co.)

ings provide a rich supplemental source of information on fatigue and creep testers.)

R. R. Moore disclosed in *Baldwin-Southwark* (the well-printed house organ of the firm of that name) his latest rotating beam fatigue testing machine which operates at 10,000 r.p.m., and takes shorter specimens. The same organization brought out in 1938 the "Rayflex" testing machine which vibrates specimens at their own natural frequency.

Among special fatigue testers taking actual parts instead of standard specimens, we may mention the machine described by F. Buckingham in *Steel* for April 3, 1939. This machine subjects "any part from a motor car or truck" to reciprocating motion; not only is the stroke controlled but the machine is of the constant stress type (as is an ordinary dead weight tester) rather than of the constant strain type which is the general characteristic of dynamic testers.

The Templin "precision metal working machine", as it is called, was unveiled at the Aluminum Co. of America's research laboratory last year — notable for its size, accuracy and adaptability.

Measurement of Metallic Properties

Work Brittleness is the property measured by a new method (rather than a new instrument) described by Graham and Work of Jones & Laughlin Steel Corp. at the 1939 A.S.T.M. meeting.

No review of recent testing progress would be complete which did not mention two features of the 1938 A.S.T.M. meeting: The 1938 Edgar Marburg Lecture by the lamented Albert Sauveur on "The Torsion Test" and a thought provoking paper by Sam Tour on "Utility and Non-Standard Impact Testing".

Wear — Details of the Skoda-Sawin hard-disk wear tester were disclosed in a communication to *Le Génie Civil* of Jan. 14, 1939, by Prof. N. Sawin himself, who reported also a number of practical results. His method would seem to give more consistent determinations (agreement of readings on specimens known to be identical) than are given by most previous machines for testing surface properties.

Among other special wear testers are those for gears. These are beginning to be rather sharply divided into *(a)* those for testing all teeth of a gear wheel in rapid succession under simulated conditions of use; and *(b)* those which determine scientifically isolated properties by simulating only one combination of conditions on only one specimen at a time. A highly perfected example is the Brown-Boveri testing apparatus for gear material described by A. Meldahl in the longest article on this subject ever published by *Engineering* (July 21, 1939). Precise control is provided of the lubrication, rolling, sliding, velocity, angle of contact and other pertinent factors.

Machinability is being accepted as a property of matter which may be quantitatively defined — this is the gist of an article in *American Machinist* for Sept. 6, 1939, by H. A. Reece, who describes the transformation of a drill press into a genuine measuring instrument capable of reproducibly reporting "machinability ratings". A lathe for similar service was exhibited in operation by the U. S. Steel Corp. at the last ASM Metal Show.

A tester for bearing metal which simulates operating conditions in an internal combustion engine was described in *Automobile-Technische Zeitschrift* by Heinz O. Heyer, and a two-page abstract in English appeared in the Feb. 5, 1939 *Automotive Industries*.

Damping Capacity — One property which remains elusive, so that it is difficult even to design an instrument that will test it alone, is damping capacity (otherwise known as internal friction or mechanical hysteresis). There was published in England a thorough discussion, a report of lengthy investigations, and a description of a new apparatus which is an obvious improvement over the Föppl-Pertz machine in that the machine does not measure its own damping capacity. (See G. P. Contractor and F. C. Thompson, *Journal* of the Iron and Steel Institute, Vol. 141, 1940.) The apparently logical solution was presented in a Japanese journal, which we chanced upon several months ago but have not been able to locate since; namely, to make the specimen integral with its own base instead of clamping it. The specimen and its base look like a thin sword-blade sticking up from a massive chopping-block.

Hardness — A discussion of all recent trends in hardness testers would fill a dozen pages. The instrumentizing trend is chiefly apparent in its third phase, namely, automatization. However, the recent improvements in fundamental measurement principles and special measurement devices — for the indentation, impact, scratch and other basic methods — deserve a passing mention. *(Cont. on p. 642)*

IN DEFENSE . . .

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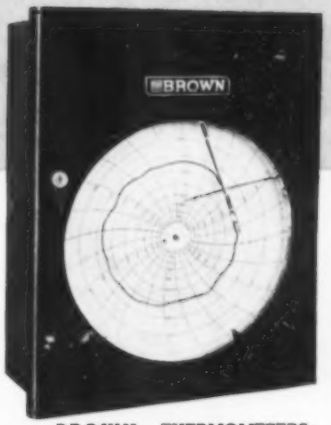

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couples, protecting tubes, leads, etc. Their practical field experience qualifies them to offer technical assistance.

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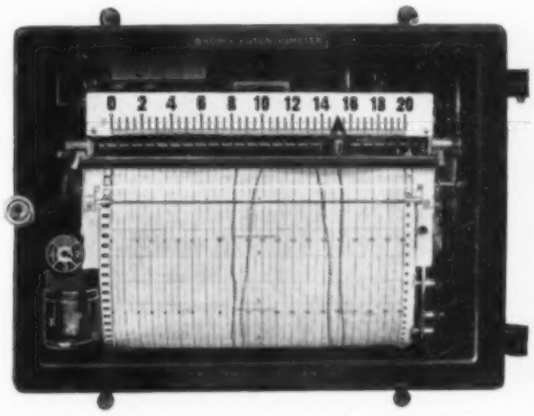

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At the National Metal Congress and Exposition, Booth 63, Philadelphia, the following Brown Instruments will be on display: New Continuous Balance Circular Chart Potentiometer . . . Radiamatic Pyrometer . . . Program Control Potentiometer Pyrometer . . . Proportioning Control Potentiometer Pyrometer . . . Multiple-Recording Potentiometer Pyrometer . . . Protectoglo System . . . Thermometers and Pressure Gauges. Write for catalogs.

CONTROLLERS
CONTROL SYSTEMS

Control is to Economize

Instruments

(Continued from page 638)

Before particularizing, mention should be made of the excellent serial on "Hardness and Hardness Measurements" which ran in *Instruments* during the last four years by Prof. S. R. WILLIAMS (shortly to be brought out in book form by the ASM).

Some of the newer basic methods have been embodied in instruments rather than in machines. This is particularly true of new micro-hardness methods. First disclosure of the Knoop Diamond Indenter appeared simultaneously in "Critical Points" of METAL PROGRESS and in the paper by KNOOP, PETERS and EMERSON in the *Journal of Research* of the National Bureau of Standards for July 1939. As many readers know, individual grains of metal may be tested for their hardness. What we found most interesting as throwing new light on the meanings of hardness measurements by indentation methods was the photograph of the indentations in (not "on") the polished surface of a diamond!

Another new hardness instrument — which no one would call a machine — was described in *Zeitschrift für Metallkunde* in February 1940 by HANNEMANN and BERNHART. It is a combination microscope and diamond-indenter tester wherein the diamond is carried at the center of the object lens. This instrument also tests a single grain.

Hardness testing of specimens heated to 2000° F. is the purpose of the pendulum design of an impact tester combined with a roll-away furnace described in *Stahl und Eisen* by H. CORNELIUS and W. TROSSEN. J. H. HRUSKA in *The Iron Age*, Feb. 1, 1940, made an eloquent plea for the combination diamond pyramid indenter and Rockwell method.

Impact — As in machines for testing damping capacity, so is there an element of inaccuracy in any of the conventional notched bar impact testers due to the impossibility of using an anvil of infinite weight and of infinite rigidity. There was brought out in England the Hounsfield Balanced Impact Tester in which this source of error is claimed to be not merely minimized but eliminated by the expedient of employing two equal masses moving at the same speed in opposite directions. Among other advantages listed in the description, which appeared in *The Automobile Engineer* for January 1938 are greatly reduced weight (and cost) and increased relative velocity. The blow is struck at 22.7 ft. per sec., the equivalent of a weight falling from a height of 8 ft.

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A wonderful article on welding and cutting in the ship yards was planned and prepared for this issue of Metal Progress, but became bogged down in the routine of necessary official releases. The following notes, written four months ago, have run the gantlet!

Welding on the West Coast

(Ships for Air and Water)

To THE BUSY PLANT of Western Pipe and Steel Co., during an all-too-short visit in San Francisco, and tried to absorb a thousand details of how to build an all-welded ship — I mean "all-welded", not a hybrid, and a 450-ft. cargo ship, not a tug boat. Backed by shipbuilding experience gained during the first world war, a generation of intervening work on large welded pipe, tankage and steel structures, and the full approval of the U. S. Maritime Commission, construction of C-1B diesel-powered cargo ships started here early in 1940....To make one of them, nearly 150 sub-units (double bottom sections, decks, bulkheads) are assembled and completely welded in the shops, leaving the ship ways free except for the assembly of these sections, the welding of side plates (strakes) to the frame members and stern frame, and the construction of the engine foundations. A careful program of sequence and direction of welding avoids warpage of each sub-unit, and is more than ever necessary for their assembly into a ship's hull. In general, welding is done from center toward end of seams, and welders always work in pairs in symmetrical portions of the sub-unit. On the engine foundation, for example (which is a cellular structure 45 ft. long, 19 ft. wide and 9 ft. high, weighing more than 60 tons) most of the intersections are "stars" — that is, the girders and diaphragms intersect at right angles, where "balanced welding" can be done by two men on diametrically opposite sides of the same intersection. When all the work was completed on this massive unit, the foundation pads for engine and reduction gear were lined up and ground to 0.001 in. (which specification really means "within the accuracy of the measuring devices available")....Welding on the assembled hull starts at center bottom and works up, sideways and longitudinally, so there is eventually a pyramid of completed structure, widening out toward bow and stern. Six transverse "expansion joints" are provided in tank-top and each of the three decks. These were really butt joints with back-up plates which are closed only when they are shaded and cooled by the structure above them, and after the portion amidship has been completely faired up and welded....So much welding, piece by piece, is done at the stern that pessimists looked for a rise of several inches. It actually amounted to 1⅝ in.; accurate location of a main reference point on the hull at frequent intervals, day and night for a couple of weeks, showed it to wander around like a fly in a 1½-in. ball; the ship is constantly on the move from wind, sun, shadow, fog and rain as much as from welding stress.... Heaviest welding was on the cast steel stern frame. It is delivered in four pieces; joints in

All-Welded Cargo Ships

Some Critical Points

By Ernest E. Thum
Editor, Metal Progress

these 20×30-in. members are made (after preheating the butts to 300° F.) by two welders working opposite; squads work continuously for about 20 hr. Each pass is cleaned, slightly peened to counteract shrinkage stress, and the next pass immediately started. Each joint requires about 100 lb. of welding rod....An undue amount of flame cutting is needed to reduce ship and structural shapes to tees and angles suitable for welding. Apparently no steel company has yet been foresighted enough to roll special shapes; now it is probably too late. For this reason the maximum saving in weight cannot be achieved; furthermore, an inordinate amount of scrap is produced. However, many counterbalancing advantages accrue to the welding method, once the shipfitters are trained to get along without erection bolts. Not the least is the ability of a crew of about 200 welders to launch a hull 80 days after the keel is laid.

Continuous Welding on Stern Frame for 20 Hours

REVISITING aircraft factories on the West Coast after three years, was impressed by the progress toward mass production. *Then* every job seemed to be different from its neighbor and was built up piece by piece; *now* huge plants like Boeing's in Seattle — prototypes of factories mushrooming throughout the central West — are tooled up for just one or two models, and these are constructed section by section complete, finally to be merely bolted together. Large shops to the rear make and finish the individual parts and even small sub-assemblies, giving a steady flow through reserve stores to larger jigs for the wing tips, engine section, tail and body units, these moving forward to final assembly and fitting. . . . Douglas in Santa Monica, for instance, has a long overhead conveyor line for engine nascelles and the inboard section of the wing holding it. There are 50 or more stations where definite things are done; periodically everything moves ahead one station. In Southern California, thanks to its salubrious climate (you've probably heard of it), much of the finishing is done out of doors, working around the clock. Long lines of aircraft, parked tip to tip, along a runway, seemingly ready to fly, impress the most casual observer that USA's reputed goal of 50,000 defending airplanes is within sighting distance.

Aircraft in Mass Production

STRUCK by the extensive use of assembly jigs and templets. Even small parts will be jigged together, templets placed, holes drilled at high speed, the unit disassembled, chips cleaned out, reassembled and riveted. Some automatic riveting machines, either of guillotine or alligator frame, can be seen, but the A. O. Smith Corp.'s plan of blowing rivets into the holes one by one, right end to, has apparently not been adopted. Major units of the craft are jigged similarly, usually starting off in half — top half and bottom half of a wing in two different jigs, for instance — so the workmen can get at both sides of a surface, and install all piping and wiring conveniently. Some of these assemblies are exceedingly complex; architectural draftsmen are employed to make perspective renderings of many of them, not only to check for interferences, but to make a drawing that the beginner can "read"..... Amazed to see as many as 30 men, working elbow to elbow around these jigs. It is doubtful if a mathematically correct solution of the problem of production is possible — that is, to subdivide and man the various operations so that the man-hours lost during transfer of subassemblies may be at a minimum. For instance, it takes one hour to dismantle a fuselage jig (big as a four-room cottage) so the completed part can be run out, and reassemble it ready for the next ship, and three quarters of the men normally working at that station can do little except check over the supply of new parts or do emergency work in the neighborhood.

Jigs, Small and Large

HAD NO TROUBLE in finding a sharp division of opinion on the question of riveting versus spot welding of thin aluminum sheet. The proponents of riveting point out that welding machines, being heavy and stationary, must operate on parts small enough to be moved up to them. Likewise, they emphasize the cost of the careful cleaning necessary before a good weld can be made, and the much greater difficulty in welding the favored alclad than the "bare" sheet. They point out that a skilled team of workmen can drive perhaps 1000 rivets an hour on accessible seams. Only 1 or 2% of the rivets are in cramped positions, hard to drive, and since they represent half the cost of the entire operation, good design is constantly cutting down the number of these trouble-makers. They couldn't

Riveting Versus Welding Alclad

Sub-Assemblies and Parts Are Stored at the Side, to Feed This Conveyor Line of Douglas Wing and Motor Sections. (This line is really three or four times this long; it turns the far corner and goes on and on.)

be welded, anyway....However, it is apparent that welding is being rapidly extended. Alclad is welded almost exclusively at Lockheed Aircraft Corp. at Burbank, for instance. Spot welding is largely limited to non-structural parts and to secondary structures such as window-frames, fairings, and doublers on cowling. Practically no non-alclad parts, such as extrusions, are welded. Approvals are being requested on the gradual extension of welding to primary structural parts such as sheet-stiffener combinations and reinforcements on ribs. No spotwelding of critical points of attachment, such as ribs to skin or wing to fuselage, is as yet considered good engineering. Many possible applications are precluded at present by the difficulty of taking large assemblies to stationary welders. As yet, portable gun type equipment has not been completely developed for the high currents and pressures required in welding aluminum alloys....An automatic cleaning and etching "line" has been established at Lockheed with a conveyor system moving parts to the tank and the rinsing sprays. A dilute solution of hydrofluoric acid has been used in the past, although a proprietary solution is now being tried....Fouling of electrode tips has been combated by many devices: Sheet has been more carefully cleaned; pressure has been increased; electric currents more precisely controlled; flat electrodes used on bottom anvil wherever possible; correct electrode materials found; disk electrodes used for spot welding long seams (making as many as 7000 spots per hr., and continuously brushed clean as they rotate). At Consolidated Aircraft Corp. in San Diego, a rotating tool clamped between electrodes is used for frequent cleaning; under proper conditions 1000 spots can be made before more complete dressing is needed.

REMINDED that W. F. HESS is heading up some intensive research at Rensselaer Polytechnic Institute into the performance of a conventional a.c. spot welder as well as the condenser discharge equipment of Taylor-Winfield and Sciaky. Some preliminary results on work done by the a.c. machine indicate that the first half-cycle of current is of the most importance in welding alclad sheet. Under these almost instantaneous conditions, the friction and inertia of the clamping mechanism would appear to be of great importance. Likewise, dome-shaped electrodes with 2 to 4-in. radius are much more satisfactory than flat-bottomed cones (which rapidly become rounded, anyway). . . . .

Instantaneous Heat Makes an Aluminum Weld

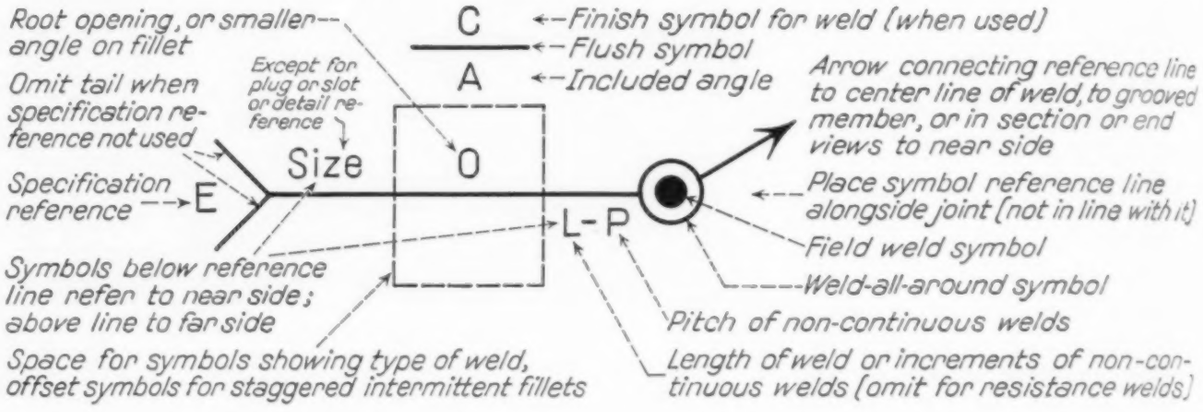
Cracked spots — that bane of aluminum welding — usually occur at the center of the weld at right angles to the surface, and fortunately are open to inspection. Professor HESS is of the opinion that they are shrinkage cracks to be expected when any small spot is rapidly heated and cooled in the midst of a surrounding rigid and cold plate. On this basis cracked welds may be (and are) mitigated in practice by easing the thermal gradient (more current into a wider area), and by peening the cooling metal (holding the correct pressure on the correctly shaped electrodes for a consider-

Welding Symbols

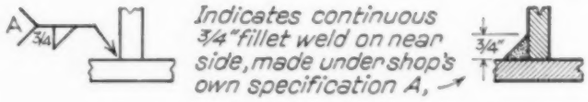
Adopted as Standard by American Welding Society, 1937

For Fusion Welding								For Both			For Resistance Welding			
Type of Weld											Type of Weld			
Bead	Fillet	Groove					Plug & Slot	Field Weld	Weld All Around	Flush	Spot	Projection	Seam	Butt
		Square	Vee	Bevel	U	J								

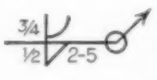
Standard Location of Information on Welding Symbols


Root opening, or smaller angle on fillet
Omit tail when specification reference not used
Specification reference
E
Except for plug or slot or detail reference
Size
C
Finish symbol for weld (when used)
Flush symbol
A
Included angle
O
L-P
Arrow connecting reference line to center line of weld, to grooved member, or in section or end views to near side
Place symbol reference line alongside joint (not in line with it)
Field weld symbol
Weld-all-around symbol
Pitch of non-continuous welds
Length of weld or increments of non-continuous welds (omit for resistance welds)
Symbols below reference line refer to near side; above line to far side
Space for symbols showing type of weld, offset symbols for staggered intermittent fillets

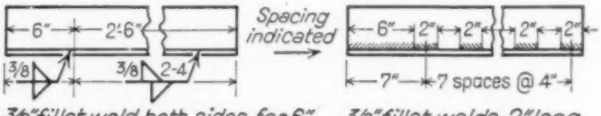
Significance of Typical Combinations



Indicates continuous 3/4" fillet weld on near side, made under shop's own specification A,

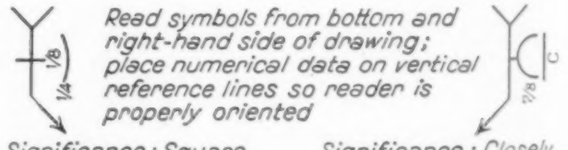


Significance: Weld all around (encircling member as far as possible). Near side: 1/2" fillet, 2" long, 5" on centers. Far side: plate has 3/4" J groove (shop's standard), continuous weld



3/8" fillet weld both sides for 6". Welds on both sides are same size unless noted

3/8" fillet welds 2" long, 4" on centers, opposite sides staggered

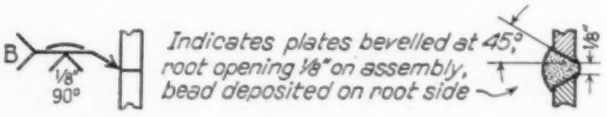


Read symbols from bottom and right-hand side of drawing; place numerical data on vertical reference lines so reader is properly oriented

Significance: Square edges on plates clearing 1/8", welded from near side, 1/4" penetration required

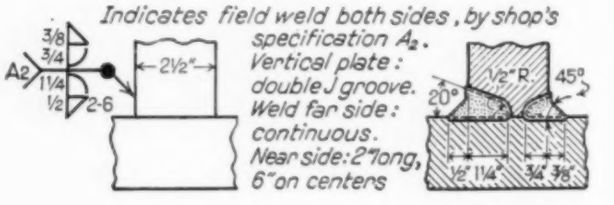
Significance: Closely abutting plates with U groove 7/8" deep, near side chipped smooth

When one member only is to be grooved arrows point to that member, thus:

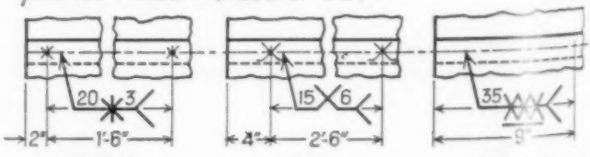


Indicates plates bevelled at 45°, root opening 1/8" on assembly, bead deposited on root side

Symbols govern to break in continuity of structure or to extent of hatching or dimension lines. Strength of resistance welds in hundreds of pounds noted instead of size:



Indicates field weld both sides, by shop's specification A_2. Vertical plate: double J groove. Weld far side: continuous. Near side: 2" long, 6" on centers



2000-lb. spot welds, @ 3" centers

1500-lb. projection welds @ 6" centers

3500-lb. seam weld 9" long, flush ne... side

For other combinations see "Welding Journal", June 1937

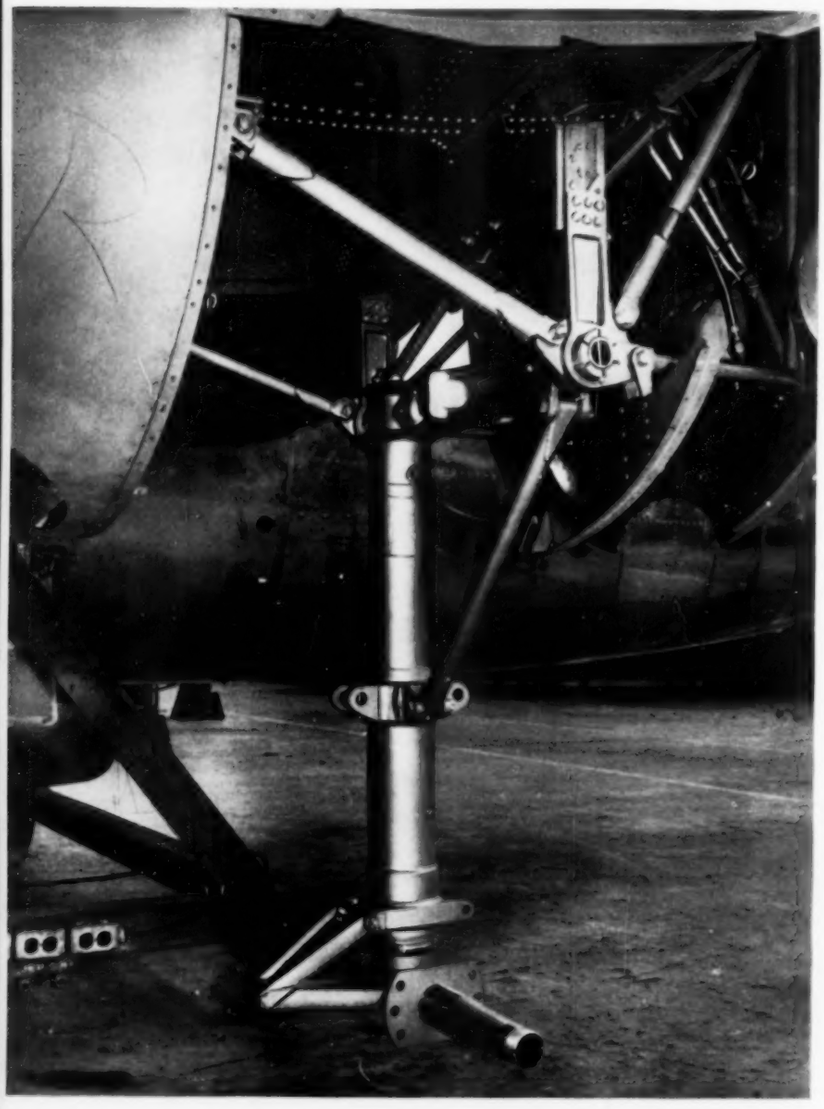
able time). It is probably well known that important features of the special spot welders built for aluminum are the exact sychronization of pressure and electrical discharge, and the subsequent variation of pressure intensity.

Noted that it is one thing to make up a single spot welded joint by laboratory methods and expert attention, but an entirely different thing to make 300 of them in the shop and satisfy the inspector. At Lockheed the supervisor sets the pressure and current cycle for the new job, and adjusts the machine to weld satisfactorily the thicknesses involved. As a preliminary check on the machine setting, a long seam is welded in material similar to that of the part about to be fabricated. This seam is then ripped apart by a motion similar to that which would be employed in unfastening a row of glove fasteners. If the welds are sound, the cast weld slugs will pull completely out of one sheet, leaving it perforated. The slugs will remain integral with the other sheet in the form of "buttons", which if uniformly large in size and regular in shape indicate that the welds are probably satisfactory in strength. When the machine appears to have been properly adjusted according to the above rough test, several single-spot shear test specimens are made up using the same machine settings, and the inspector "pulls" them on a hand operated testing machine located near the spot welding equipment. If none is below the specification minimum, the work of welding the part is then allowed to proceed. It has been verified many times that (except for abnormally close spot spacings) the single-spot test specimens are reasonably indicative of the strength per spot to be found in a multiple-spot joint. For research purposes, however, shear test specimens are usually made up by cutting an entire seam into single-spot specimens; but this is seldom feasible in production work....Several types of fatigue tests have been devised at Lockheed's structural laboratory for studying the endurance of spot welded joints under repeated or cyclically varying stress. Structural members such as box beams and skin-stiffener assemblies have been made up and subjected to repeated bending and vibration; also, single spot specimens have been subjected to torsional fatigue by twisting the ends of the strip in opposite directions. In general it appears that the fatigue endurance of a spot welded joint is comparable to that of a flush-riveted joint....Remembered having seen at the Boeing plant in Seattle aluminum wing surfaces lapped and welded in four rows of spots, to make a big sheet whose thickness varies according to the stresses it must carry. Such a joint is from 80 to 90% efficient in tension tests. Also saw there an automatic arc welder building fuel tanks of fairly thick aluminum sheet.

Inspected Spot-Welded Assemblies

Inspecting the enormous Boeing plant in Seattle with Frank Bolte, process engineer, was impressed by the reliance on d.c. arc welding for engine mounts, struts, and other fittings made of X-4130 tubing and plate. Almost every place else this is done with the oxy-acetylene flame, but arc welding was established here almost 20 years ago, and does a very smooth job. Lime-dipped, low carbon steel electrodes are used (no alloy), and sufficient extra metal is put into the seam to care for its lower strength and minor porosities. For small, light gage work (as thin as 0.016 in.) the welding generators must operate quickly and smoothly on currents as low as 5 amp.—although for the usual thicknesses of 0.058 in. and over, 20 to 25 amp. are used. At the upper end of the scale is 1⅛-in. (yes 1⅛-in.) chromium-molybdenum steel plate welded into the landing gear of a 75,000-lb. ship....The work-holding jigs are most ingenious and carefully engineered; Bolte also emphasized that a correct welding routine must be worked out. Tolerances on a completed engine mount are plus or minus $\frac{1}{32}$ in., yet there may be as much as ⅛ in. movement during welding in a single sub-assembly....Welded assemblies of alloy steel tubing are not heat treated or even stress relieved by Boeing, Bolte explaining that no service failures had ever been attributable to internal stresses. Many precautions in design and fabrication are necessary to avoid harmful concentration of stress, but when these are taken and the finished part given a careful magnetic inspection, it will be quite satisfactory. Undue stresses show up unmistakably in warpage easily discoverable by size inspection....Observed some exceedingly interesting equipment for slitting, nibbling and sawing tube ends so they fit neatly into the peculiar intersections. Close and accurate fit is essential; each set-up is inspected and approved before any welding is done on it....At Vega Airplane Co. (Bur-

Arc Welded Steel Tubing



Struts on Landing Gear (as Well as Intricate Assembly for Engine Mounts) Are of Arc Welded Steel Tubing and Forgings. (Photo courtesy The Lincoln Electric Co.)

bank) arc welding is also favored. If forgings are welded to tubing and the metal thicknesses are different, the forging would be mildly preheated, say to 300° F. Furthermore, many joints are stress relieved by local heating to 500 or 600° F. immediately after welding is completed, and cooled in the jig....At Douglas (Santa Monica) a multitude of flash butt welds are made in push-pull rods between X-4130 tubing and forged end fittings. I was told that this has five times the endurance to alternating loads of a fusion weld, and makes a 100% joint by all other tests. The hardened zone from the heat effect is almost imperceptible. Douglas engineers are talking of such joints in landing gear and tail mounts. In England it is said that rather intricate weldments of telescoped tubes and plate are substituting for forgings, which are scarce and usually heavier, but over here the trend is in the opposite direction.

AT DOUGLAS Aircraft Co.'s plant in Santa Monica found the huge B-19 attracting more visitors' attention than the two-engined bombers rolling off the line every six hours. Wondered about the ultimate size of these mammoths (no, we have to invent a word meaning huge bird, maybe the "roc" of the Arabian Nights will serve; it fed elephants to its fledglings). Ultimate range? Around the world, non-stop to home base....After much seeking and telephoning found STUART OLIVER, formerly metallurgist of Delco Products of Dayton, in the tooling department — a most impressive plant within a plant where all the jigs, fixtures and special devices are engineered, constructed, and made to work interchangeably in main and all branch factories. ARTHUR KLEIN, who divides his time between Douglas's engineering department and the Guggenheim aeronautical laboratory at Caltech, was my stimulating guide. While present designs are "frozen" to the extent that nothing can interfere with production of completed ships, he cited the clear trend of Douglas design to avoid strength members built up of sheet by substitution of large extrusions.

Machining at Speeds Cyclonic

the simplification of wing structures by using larger main members and fewer secondary members, and the elimination of small parts such as attached stiffeners by pressing flanges and corrugations into the diaphragm itself....Amazed at the speed at which these 24S aluminum extrusions are milled down to the correct taper. No coolant is possible on milling cutters running at top speed and reducing 100 cu.in. of metal to fine chips per minute. Innumerable shapes are also cut out of stacked sheets by routers mounted on pantagraph arms. The cutters run at 15,000 to 18,000 r.p.m., so fast that a water-cooled motor is required. Limiting speed is not the machinability of the metal or the cutting power of the toolsteel edge but the failure of the motor bearings. The optimum speed of the cutting edge is unknown, but several thousand feet per minute has been reached on large fly cutters, and if the blades foul it seems to be a defect of the tool shape rather than a character-

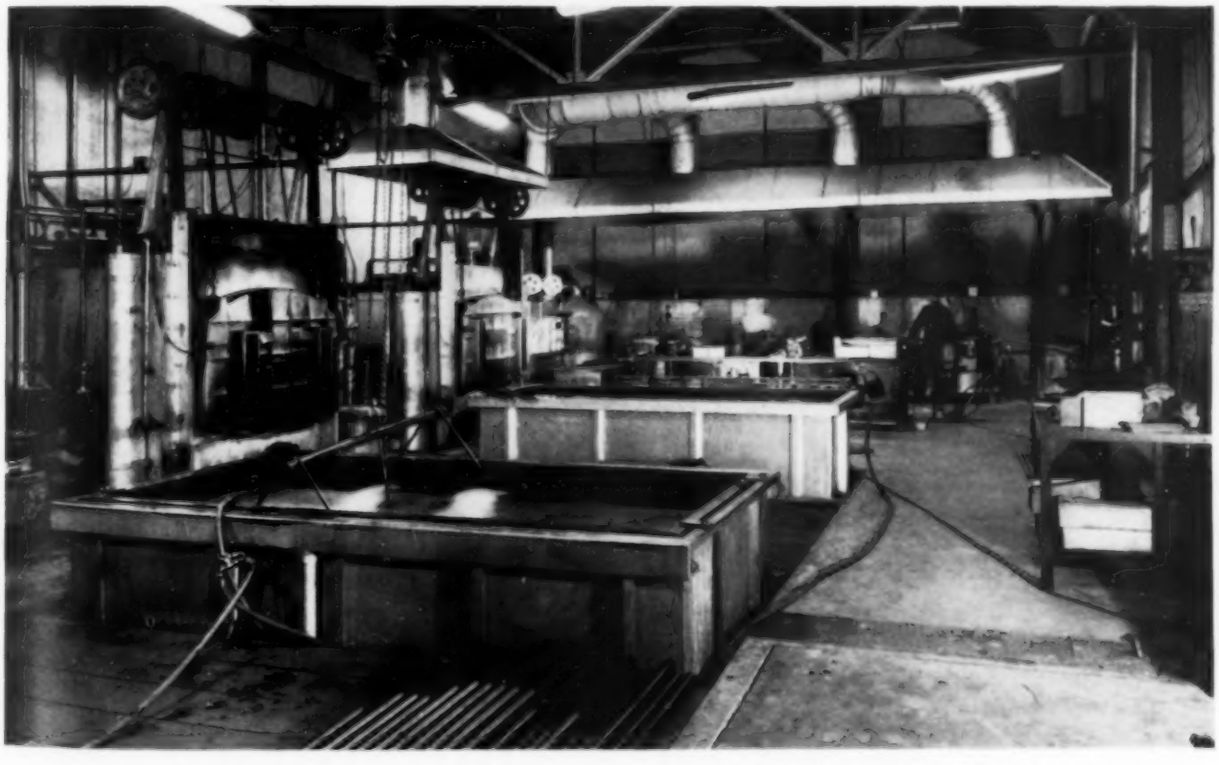
istic [illegible] the aluminum alloy being cut.... KLEIN think[s] that a more extensive use of heat treated or w[e]lded steel in aircraft structures would be a ste[p] backward. However, he is equally sure that [t]he strong aluminum alloys 17S and 24S, so widely used, are by no means perfect. The wrought alloys 51S, 53S and 61S are much more workable and, having no copper (or very little), are so much more corrosion resistant that alclad and the extra prompt and severe quenching required for alloys 17 and 24 are unnecessary. Unfortunately their strength is not so high, and full aging requires 18 hr. at 320° F., hence large heat treating space.

WAS REMINDED that the plea for steel wing spars for big aircraft, as a method of conserving scarce aluminum (METAL PROGRESS, August issue) could have been reinforced by reference to the Boeing four-engined bomber ("The Flying Fortress") which already uses X-4130 tubes, heat treated to 190,000 psi. for main wing spar center sections, gusset plates, and inboard terminals. Shear connections on the inboard wing and the outboard wing joints are from X-4130, and all connection bolts of alloy steel. Engine mounts, landing gear and retracting mechanisms, tailwheel assembly and tail attachments are also of X-4130 or X-4340.

Steel in Aircraft Structure

(The industry is indeed to be congratulated on concentrating its medium alloy steel requirements mainly on but two or three alloy steels, chromium-molybdenum and chromium-nickel-molybdenum.)....As to the use of stainless steel, it is standard for firewalls at the rear of engine mounts, and for exhaust manifolds. (Inconel is sometimes used for the latter.) On the big Boeing bomber the inner cowling and shrouds over the exhaust stacks are all stainless. No less than 24 details of aircraft and armament fittings, made of 18-8, were on exhibit at the Western Metal Congress.

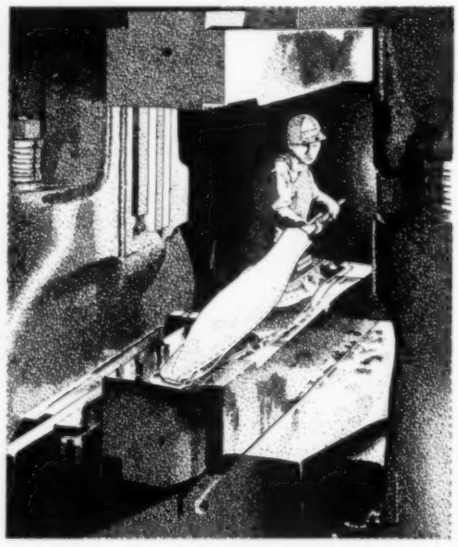
NOT WITH THE IDEA of belittling the excellent aluminum alloys so widely used for aircraft, but in the hope that the supply may be eked out, one thinks of the silver-magnesium alloy now being built into experimental wings for static and flight tests. ARTHUR WINSTON.



One End of the Steel Treating Department at Boeing's Seattle No. 2 Plant. Special attention has been paid to ventilation, so as to prevent ammonia and salt-pot fumes from entering surrounding departments. (Photo courtesy The Austin Company).

metallurgist for Dow Chemical Co., in his lectures on magnesium at the Western Metal Show, said that the addition of 6% silver to Dowmetal "X" (3% Al, 3% Zn, 0.2% Mn) produced the strongest magnesium alloy yet found. In extrusions it is heat treatable to a tensile strength of 55,000 psi., yield strength of 45,000 psi., and elongation of 7%, which is within reach of the commonly used 24S-T aluminum alloy extrusion (60,000, 44,000, 12% respectively), weighing 50% more. This silver alloy is not yet adaptable to magnesium sheet; the best material which is workable is considerably weaker than alclad 24S-T sheet, so no weight can be saved in the skin, but the added thickness of equivalent magnesium sheet is of measurable value because of its greater stiffness under compressive and shear loads....Six per cent of silver in an extrusion alloy for structural purposes, might look like getting beyond the bounds even of a wartime "economy". It would take a little less than a troy ounce of silver for a pound of alloy and would about double the cost of the magnesium alloy in ingot form. (There is plenty of silver available; new metal is produced in the Americas at the rate of 200 million ounces yearly, and two thirds of it has no use.) If a 6% silver alloy saves weight, it will doubtless be worth the cost. While the value of weight saving in military aircraft is unknown, it is probably no less than its value in commercial ships. ARTHUR KLEIN of Douglas Aircraft Co. has figured this out for transports on the basis of 5 yr. life, 8 hr. daily flying, and the income per pound of dead load comes out to be about $35 per *ounce* — so weight saving is literally worth its weight in gold....This gives a new slant on the insistence on small drafts on aircraft forgings and close tolerances on aluminum alloy sheet. For instance, a wing covering may be 0.025 in. ± 0.002. This is a pretty close tolerance for the mills when rolling wide sheets, but the plus variation may run to 8% of the expected weight.

Interesting Magnesium-Silver Alloy



IN THE DOUGLAS PLANT, was shown a battery of five heat treating furnaces for sheet steel pressings. They were made by the tooling department. Each one is long and narrow, but high enough to take a crate in which may be carried full-sized sheets of aluminum alloy, edges up. These crates or racks are carried on overhead trolleys; at the end of the heating cycle the door opens, the trolley rolls out, strikes a trip and the rack drops into a tank of cold water. Total time, 7 sec. — for speed is essential in quenching bare 17S and 24S, else the corrodible copper constituent will collect at grain boundaries rather than be held in solid solution. One of the five furnaces can handle all the bare alloys; alclad can be cooled much slower and develop correct physicals, so the hot metal from the other four furnaces is not quenched but cooled in water mist. The racks of hot metal are run out under a hood about the same size and shape as the furnace; at the top is a series of nozzles from paint spray guns, producing a fog which gives a rather more rapid and uniform cool than if the alclad were cooled in quiescent air. The pure aluminum coating on this form of material insures corrosion resistance, and the slower cooling avoids much warping. Since both 17S and 24S age fairly rapidly at room temperature, no tempering furnaces are necessary....DWIGHT HALL, supervisor of heat treating, explained the temperature control. The work is heated by circulating air rather than in the usual salt bath. The side walls are covered with banks of resistors, placed behind baffle plates; the air is sucked down through slots in the floor, sent up behind the baffles to bathe the hot resistors, and then out exhaust pipes in the roof to pass through and heat the charge. Since the flow of hot gas is thus generally parallel with the flat material being heated, the latter acquires its temperature uniformly and quickly by convection. The resistors for each furnace are in 12 banks, each separately controlled through on-and-off contactors. Thirty-six contactors are

Heat Treating Furnace and Quenches for Aluminum

Recommended Electrode Materials

Chart adopted by Resistance Welder Mfr's Asso. for Spot Welding Similar and Dissimilar Metals When Time, Current and Pressure Are Properly Controlled and Conventional Methods and Welders Are Used.

To Weld Similar Metals

To Weld Similar Metals read block under metal to be welded.	Ferrous																Non-Ferrous																	
	Tin-Plated Steel		Terne-Plated Steel		Galvanized Iron, Zinc Plate		Cadmium-Plated Steel		Chrome-Plated Steel		Stainless Steel, 18-8 Type		Scaly Hot Rolled Steel		Cold Rolled Steel; Clean Steel		Aluminum		Aluminum Alloys, Durelumin		Cupro-Nickel		Nickel Silver; Nickel Brass		Nickel		Nickel Alloys, Monel, Nichrome (High Resistance)		Yellow Brass, 25 to 40% Zinc		Phosphor Bronze		Silicon Bronze, (Everdur; Olympic, Duronze, Herculoy)	
	B	I	A	I	A	I (II)	B	I	A	II	A	III (II)	B	I (II)	A	II	B	I (II)	B	I (II)	A	II	B	II	A	II	A	II	B	II	A	II	A	II
	I	3	I	3	I (II)	3	I	3	II	3	III (II)		I (b)	2	II		I (II)		I (II)		II		II		II		II		II		II		II	

To Weld Dissimilar Metals

Ferrous Alloys	Stainless Steel, 18-8 Type		Chrome-Plated Steel		Cadmium-Plated Steel		Galvanized Iron		Terne-Plated Steel		Tin-Plated Steel	
Cold Rolled Steel; Hot Rolled Steel, Clean	A	II (III)	A	II	B	II	B	I	A	I (II)	B	I
	II		II	3	II	3	II	3	II	3	II	3
Tin-Plated Steel			B	II	B	I (II)	B	I	B	I (II)		
			I	3	I	3	I	3	I	3		
Terne-Plated Steel	B	II	B	II	B	I (II)	B	I				
	I	3	I	3	I	3	I	3				
Galvanized Iron, Zinc Plate	B	II	B	II	B	I						
	I	3	I	3	I	3						
Cadmium-Plated Steel	B	II	B	II								
	I	3	I	3								
Chrome-Plated Steel	A	III (II)										
	II	3										

Non-Ferrous Alloys	Nickel Alloys		Nickel		Phosphor Bronze		Silicon Bronze		Yellow Brass		Nickel Silver	
Cupro-Nickel	B	II			B	II	B	II			B	II
	II				II		II				II	
Silicon Bronze; (Everdur, Olympic, Duronze, Herculoy)					B	II	A	II	B	II		
					II		II		II			
Nickel Silver	B	II			B	II	B	II				
	II	1			II	1	II					
Nickel Alloys	A	II	A	II								
	II		II									
Stainless Steel, 18-8 Type	B	II	B	II								
	III (II)	1	II (II)									

Aluminum Alloys, Durelumin	Aluminum	
	B	I (II)
	I (II)	

Block Interpretation:

Weldability: A-Excellent B-Good	Electrode Against
Electrode Against	Special Information

Special Information:

1. Special conditions required.
2. Good practice recommends cleaning before welding.
3. If plating is heavy, weld strength is questionable.

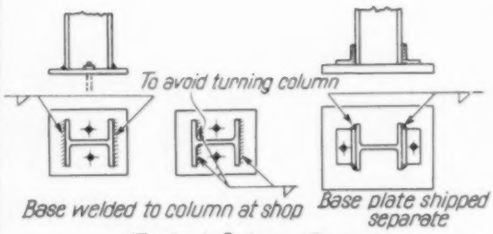
Note: Electrode materials in circles are second choice. Example: (II)

Names of Commercial Electrodes (Not a part of R.W.M.A. Standard)

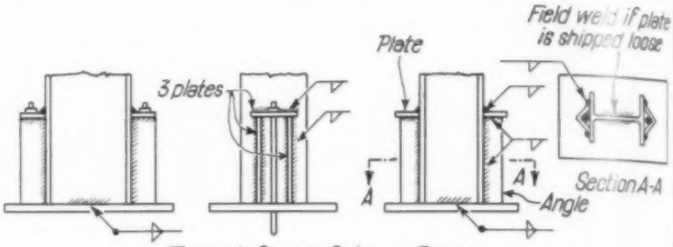
Class	Manufacturer				Special Adaptabilities
	Electroloy	Mallory	S-M-S	Welding Sales	
			Group A; Copper Base Alloys		
I	Grade A	Elkaloy A	Alloy 101	Tuffaloy 88	Coated, plated and scaled metals; aluminum
II	XX TX	Mallory 3 Tradaloy 7	Alloy 103	Tuffaloy 77	Clean Steel; yellow brass
III	TB	Mallory 100 Tradaloy 1	Alloy W5	Tuffaloy 55	Projection, flash and butt welders; stainless steel
			Group B; Copper-Tungsten Alloys		
X	Electroloy 1-W-3	Elkonite 1-W-3	Alloy 1	Tuffaloy 1-W-3	Stainless steel; yellow brass
XI	Electroloy 10-W-3	Elkonite 10-W-3	Alloy 10	Tuffaloy 10-W-3	Inserts and facings; light projection welding
XII	Electroloy 20-W-3	Elkonite 20-W-3	Alloy 20	Tuffaloy 20-W-3	Heavy projection welding; upsetting
XIII	Electroloy 100-W	Elkonite 100-W	Alloy 100-W	Tuffaloy 100-W	Red brass; copper

Welded Connections for Tier Buildings

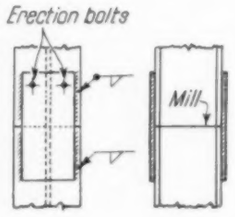
By permission, from American Institute of Steel Constuction's Tentative Standards, December, 1939



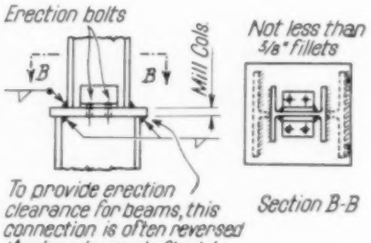
Typical Column Bases

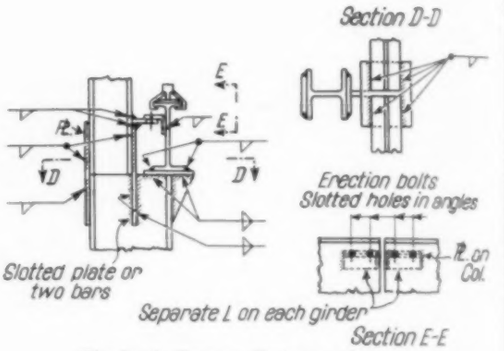


Typical Crane Column Bases

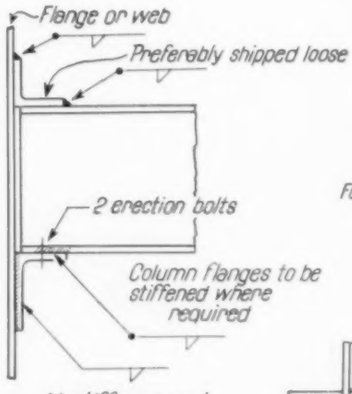


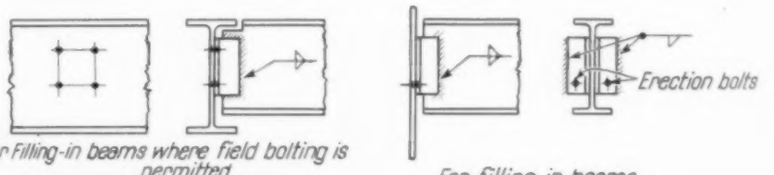
Typical Column Splices


Erection bolts
B
B
Mill Cols
Not less than 5/8" Fillets
To provide erection clearance for beams, this connection is often reversed (Angle on lower shaft, plate on upper shaft.)
Section B-B
Preferred splice (No holes in main material)

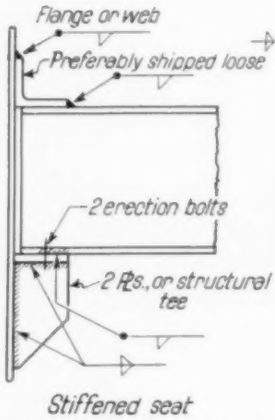


Typical Crane Column Splice

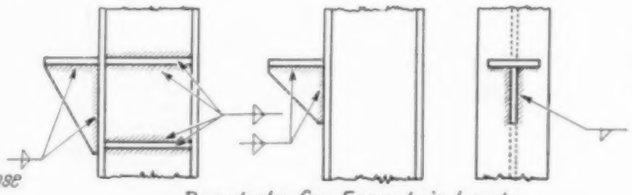




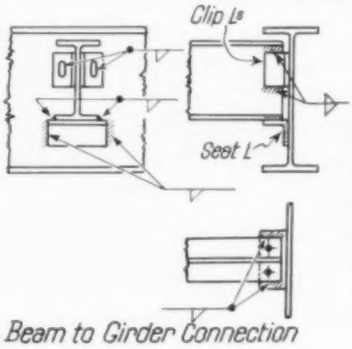
Typical Beam Details



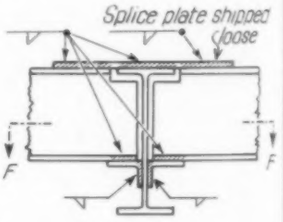
Beam to Column Connections

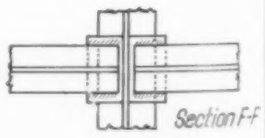


Brackets for Eccentric Loads



Beam to Girder Connection





Continuous Beam over Girder

Welds made with heavily coated electrodes only, and at temperatures above 25 °F. Fillet sizes 1/4 or 5/16 in.; lighter fillets permissible on less than 1/2-in. plate. Welded structures must conform in design, fabrication and erection to American Welding Society's "Code for Fusion Welding and Gas Cutting in Building Construction." Rigid-end beams permissible only when specially designed for. Flexible beam connections shall permit rotation of top flange-ends an amount in inches equal to flexural unit stress in psi. at mid-span times span in feet divided by the constant 3,625,000.

required, 12 thermocouples, and one 12-point controller recorder; the contactors are placed in a spiral around a drum so that each zone is successively under control and conditions checked (or changed) once a minute.

REMINDED that three years ago HENRY GUTMAN's method was new of using a pile of live rubber mats for the upper die in hydraulic presses. Lower dies for forming aluminum sheet ordinarily are of zinc alloy (see "Critical Points" for July 1940), but may now also be molded of an organic plastic mixed with wood fiber. Flat steel templets with sharp corners can be nested on the bed of a big press, a large aluminum sheet laid over them and a series of flat blanks cut with a single pressing. Likewise, aluminum sheet can be formed and trimmed at a single stroke if the blank is oversize so the outer edges can be seized between a depressed shoulder of the die and the rubber, and the taut rim forced down past square edges of steel outlining the true form of the pressing. . . . Was shown some deep and complicated draws which require double cut-offs — that is to say, the piece is drawn to about the place where edge cracking will start, this dangerous metal is sheared away by pressure as above, and without interruption the upper bed of the press squeezes on down until the form is complete and the second inner cutting edge comes into play for the final trim. Three-dimensional trim, easy under rubber with such dies, is very difficult with metal punches; in fact, wrinkled edges around deep draws made under drop hammers and triple-action presses are more easily cut away in routing machines than in dies.

Progress in Die Use and Design

ACQUIRED KENNETH JACKMAN's enthusiasm for the "Celstrain" extension gages he makes in Consolidated's test department for 20¢, weighing 0.01 oz., and capable of measuring changes of 50 psi. in an aluminum member. It is merely 1 in. of "Advance" wire cemented to the article being tested. It is forced to extend or contract with the elastic movements of the metal being tested, and the corresponding changes in cross-section of the wire are reflected by changes in its electrical resistance. This, in turn, can be read at some remote point in 10 sec. on a Wheatstone bridge, or recorded instantaneously by an oscillograph. . . . So when you see some men carrying what looks like a 'steen-tube radio set and movie camera into a ship for its trials, it means that there are hundreds of these little tell-tales fixed to important parts of the structure, and the stresses actually set up in flight will be checked against the calculations. First models may therefore be completely checked up.

Stresses Read by Remote Control

By virtue of uniform materials, precise manufacturing methods, and adequate inspection, step-by-step, it becomes less wonderful that so complicated a mechanism can be produced, time after time, without serious defects appearing in some of them on acceptance flights. . . . Various indeed are the test equipments devised for specific duties. Every structural laboratory in the aircraft industry has its "torture post" — a massive square tower of concrete anchored into a husky floor slab, all provided with numerous anchorages for hold-down bolts and loading jacks. This scheme has been extended to the extreme in tests on the new 70-ton Martin bomber for the Navy. The entire ship is surrounded by a stiff frame of structural steel, against which jacks can place any combination of loads. Maximum deflection at tip of 100-ft. wing approaches 6 ft.; changes in outer shape are measured by surveying instruments; strains

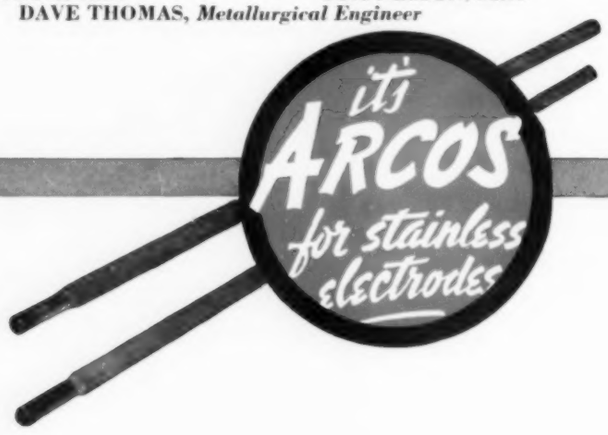
(Continued on page 669)

MORE THAN A HANDSHAKE!

Users of stainless electrodes will find a hearty welcome at the Arcos exhibit—Booth No. 12 at the Metal Show in Philadelphia. Stop in and talk with men competent to discuss both the technical and practical problems of welding with stainless electrodes. These men of Arcos will be in attendance:

R. D. THOMAS, *President*
HAROLD EWERTZ, *Sales Manager*
BILL OSTROM, *Sales*
BERT ROSS, *Sales*
ED SHOOK, *Sales*
TOM NELSON, *Sales*
DAVE THOMAS, *Metallurgical Engineer*

ARCOS CORPORATION
401 N. Broad St., Phila., Pa.



"QUALITY WELD METAL EASILY DEPOSITED"

Distributors Warehouse Stocks in the Following Cities:

ATLANTA, GA.	*J. M. Tull Metal & Supply Co.*
BUFFALO, N. Y.	*Root, Neal & Co.*
BORGER, TEXAS	*Hart Industrial Supply Co.*
BOSTON, MASS. (Belmont)	*H. Boker & Co., Inc.; W. E. Fluke*
CHICAGO, ILL.	*Machinery & Welder Corp.*
CINCINNATI, OHIO	*Williams & Co., Inc.*
CLEVELAND, OHIO	*Williams & Co., Inc.*
COLUMBUS, OHIO	*Williams & Co., Inc.*
DETROIT, MICHIGAN	*C. E. Phillips & Co., Inc.*
ERIE, PENNA.	*Boyd Welding Co.*
FT. WAYNE, IND.	*Wayne Welding Supply Co., Inc.*
HONOLULU, HAWAII	*Hawaiian Gas Products, Ltd.*
HOUSTON, TEXAS	*Champion Rivet Co. of Texas*
KANSAS CITY, MO.	*Welders Supply & Repair Co.*
KINGSPORT, TENN.	*Slip-Not Belting Corp.*
LOS ANGELES, CALIF.	*Ducommun Metals & Supply Co.*
MILWAUKEE, WIS.	*Machinery & Welder Corp.*
MOLINE, ILL.	*Machinery & Welder Corp.*
NEW YORK, N. Y.	*H. Boker & Co., Inc.*
OKLAHOMA CITY, OKLA.	*Hart Industrial Supply Co.*
PAMPA, TEXAS	*Hart Industrial Supply Co.*
PITTSBURGH, PA.	*Williams & Co., Inc.*
PORTLAND, OREGON	*Industrial Specialties Co.*
ROCHESTER, N. Y.	*Welding Supply Co.*
SAN FRANCISCO, CALIF.	*Ducommun Metals & Supply Co.*
SEATTLE, WASH.	*H. A. Cheever Co.*
ST. LOUIS, MO.	*Machinery & Welder Corp.*
SYRACUSE, N. Y.	*Welding Supply Co.*
TOLEDO, OHIO	*Williams & Co., Inc.*

Critical Points

(Continued from page 665)

on individual members by hundreds of extensometers. About $100,000 was spent on test rigs, central control stations, and testing of this craft before its power plant or any of its interior fittings were installed.

Mechanized X-Ray Laboratory

OBSERVED X-ray inspection geared to mass production in Triplett and Barton's laboratory at Burbank. Every casting going into Lockheed planes is photographed from one to several directions depending on its shape, and is approved for soundness before any machine work is done. When too much porosity or other defects are regularly encountered in too large a proportion of the parts, either the foundry practice should be perfected, or the shape is unsuitable for casting and should be forged or machined from an extrusion. ...Equipment was demonstrated by HAROLD STORM, and is mechanized to a high degree. The inspection machines for aluminum are entirely automatic. They have the appearance of small hydraulic presses. Castings are arranged on a tray above a film and the loaded platform rolled into position whereupon the X-ray tube and its surrounding lead shield lowers, the exposure is turned on and held for the correct time, the current interrupts, the shield rises, the tray of exposed material rolls back to one side, another loaded tray rolls in from the other side, and the cycle is ready to restart. All the operator needs to do is to handle the film, arrange the specimens and press the button. ...Film development is equally business-like. The two films of a single group of castings are clipped to a stainless steel frame and loaded on a conveyor like one which serves an automatic electroplating line, then up and out into the developer, fixers and washes. Solutions are constantly renewed at the correct rate, automatically adjusted to the number of films going through. Exit from the dark room is through a long drying tunnel, in which blows a vertical current of heated air....One check film for density and contrast is made for every 100 exposures, developed and measured by a densitometer — in this way the correct performance of all correlated units is verified. Every lot of film is also checked before use to determine whether it requires modification of the standard routine. . . . Films are viewed under diffused light, reported on standard forms, and all data transferred to punched cards for statistical analysis and for permanent record.

WE RENEW OUR PLEDGE

Two years ago, at the beginning of the present war with its uncertainties and threats to the future of all industry, this Company publicly pledged itself not to increase its selling prices.

On this, the second anniversary, we again publicly renew that pledge.

During the last two years we have not only kept the pledge previously made, but *we have actually reduced our selling prices by more than 6%* because of more efficient operation made possible by the marvelous cooperation and ability of our organization. This was accomplished in the face of rising labor and material costs, both of which have been increased by considerable amounts.

It is our belief that the only hope for the continuance of the present industrial system now threatened from within and without is in its ability to give more and more to the consumer for less and less of his dollar. This is the strength of American individual initiative. This is the hope of our country's future. If American industry can accomplish this universally, we need not fear dictators either at home or abroad.

THE LINCOLN ELECTRIC COMPANY

Cleveland, Ohio
October 2, 1941

J. F. Lincoln

President

*PATCHES ON SUNDAY PANTS INDICATE HEAVY CONCENTRATION ON PRODUCTION IMPROVEMENT

WHITEY SEZ: *"GOD GAVE MAN TWO ENDS: ONE TO THINK WITH AND ONE TO SIT ON. A MAN'S SUCCESS DEPENDS ON WHICH END HE USES MOST; A CASE OF HEADS YOU WIN AND TAILS YOU LOSE . . . MAURATH STAINLESS ELECTRODES LIKEWISE HAVE TWO ENDS—BOTH VERY BUSINESS-LIKE; BOTH CONTRIBUTING TO THE WELDER'S SUCCESS."*

STAINLESS Type Numbers Available		
302-B	316	330
308	316-Cb.	347
309	317	410
309-Cb.	321	430
310	325	442
311	329	446
312	•	502

15% Cr.—65% Ni.
20% Cr.—80% Ni.

HAVE A *SEAT* IN BOOTH D-31 AT THE METAL SHOW—*PATCHES FURNISHED*

MAURATH, Inc.
Builder of better welding

CLEVELAND
electrodes in all analyses

Among the group meetings or clinical discussions on conservation of strategic metals and substitutes therefor, arranged by the National Metal Congress and Exposition, is one on "Stainless and Heat Resisting Steel". Members of the information panel for this meeting have contributed the following outlines

The Stainless Steels

Their Conservation and Substitutes Therefor

THE STAINLESS STEELS or, more broadly, the heat and corrosion resistant materials, are in great measure alloys of nickel, chromium and iron. Nickel may range from 8 or 10% up to 100%; chromium from 12% up to 35%. Consequently the supply of these two metals is most important, especially since little or none is produced in the United States.

Nickel Supply

The situation in nickel has been discussed in METAL PROGRESS at intervals since February — rather extensively in the March issue — so it is hardly necessary here to do much more than give a brief outline.

In 1937 (a pre-war year of high nickel imports) we used about 83,000,000 lb. of nickel. In 1940 our imports were 141,000,000 lb. of pig, ingot and shot metal and another 35,000,000 lb. of nickel in matte destined for monel metal (nickel-copper alloy). Great increases cannot be expected soon, due to the well-balanced mining, smelting and refining operations in Canada, but OPM in August estimated current imports at 15,000,000 lb. per month (180,000,000 lb. per year). Only 1,000,000 lb. per month is now available for civilian "needs", which total perhaps ten times as much.

Where does this nickel go? Proportionate demands fluctuate with artificial conditions, as shown by the following estimate prepared in March by the Advisory Committee to OPM on Metals and Minerals. This represents the distribution of nickel deliveries among primary nickel consuming industries in the United States and Canada:

	1937	CURRENT*
Steel mills	47%	63%
Steel foundries	5	3
Iron foundries	9	6
Brass mills	8	6
Non-ferrous foundries	1	2
Aluminum alloy manufacturers	1	½
Heat resisting and electrical resistance alloys	7	5
Rolled nickel and high nickel alloys	7	5
Electroplaters' supplies	13	8
Miscellaneous	2	1½
Total	100	100

*Based on December 1940 and January 1941 deliveries.

In view of the large current importations, the actual deliveries to the iron and steel mills and foundries are at three times their "normal" rate. Likewise some 1,500,000 lb. of nickel monthly is going into resistance wire and elements and rolled nickel and high nickel alloys, which latter categories can be regarded as falling within the subject "Stainless Steels".

Lacking definite information about the real need of such a vastly increased consumption by the steel mills, one speculates that it is due to a combination of causes. First is the large demand for ordnance which specifies 3½ and 5% nickel steels much more freely than does industry. Second is an effort of users to stock against shortage. Third is the large increase in nickel

locked up in process and in warehouse and transit.

As to its actual consumption into stainless steel, the above-mentioned committee estimated that "it is probable that about 20% of the current supply of nickel to steel mills is used for stainless steel production, as compared with a normal figure of perhaps 25%." On the basis of imports of 180 million, this roughly checks a recent estimate of the American Iron & Steel Institute: "In 1940 American steel plants produced a quarter of a million tons of stainless steels, and output this year is at an even higher rate." What can be done about conservation and substitution will be the main theme of the subsequent notes.

The National Academy of Sciences through its National Research Council was asked several months ago by the Office of Production Management to organize an Advisory Committee on Metals and Minerals which could report to them on questions of proper use of scarce materials and possible means of conservation and substitution. CLYDE E. WILLIAMS, director of Battelle Memorial Institute, is chairman of this main committee and ZAY JEFFRIES, technical director of the lamp division of General Electric Co., is chairman of its subgroup on metals. In response to request, a report on chromium was prepared by A. B. KINZEL, chief metallurgist of Union Carbide and Carbon Research Laboratories, circulated to the members of the subcommittee, revised according to their comment and criticism, and submitted to the OPM on July 25, 1941.

Chromium Supplies and Consumption

by Advisory Committee to OPM on Metals

FERROCHROMIUM is being currently supplied by the United States industry at the rate of over three times that of 1937 and over four times that of 1929, the chromium production in 1937 having been the highest of any year prior to the present upsurge of demand. Today industry is consuming chromium at the current rate of production and would absorb more were it available. By judicious use of chromium the steel industry has prevented serious shortage in any one spot, so that as yet the situation is not highly critical. This is true in spite of the extraordinary increase in production of stainless and engineering steels and the export of both chromium steel and ferrochromium to Britain.

Three major items are involved in the supply of ferrochromium — adequate ore supply, adequate smelting and processing equipment, and adequate electrical energy. Large stocks of metallurgical ores were available in January, 1940, and the rate of importation of ore in 1940 was such that by January, 1941, there was only a slight decrease in stocks of metallurgical ore. It is significant that the rate of import has been maintained at a high level in the first third of 1941. Thus, as long as the present rate of import is maintained the ore situation is not a source for concern even though the increase in consumption should be somewhat greater than that large increase which is expected. Moreover, even with decrease in the rate of import the stocks are such that there would be appreciable time in which to work at the problem.

As to the manufacturing facilities, Table 1 shows the estimated shipments of ferrochromium and contained chromium by years since 1937, and it will be observed that the 1940 figure is over 2½ times that of 1937. It will further be observed that the annual rate of production for the last quarter of 1940 is only three-quarters of the projected rate for 1941, 160,000 gross tons of 70% ferrochromium. As the actual smelting and refining rate at the beginning of 1941 was approximately 150,000 gross tons it will be appreciated that the situation is close to critical from the standpoint of production. However, additional capacity now under construction will bring the production capacity to 190,000 tons per year by the end of the year and some of the new capacity will be available during the year. The capacity is well divided between the low carbon, 0.04 to 2% carbon, and the higher carbon grades.

Table 1 — Ferrochromium Production

	Gross Tons 70% FeCr	Contained Chromium
1937	45,000	70,500,000 lb.
1938	20,000	31,400,000
1939	50,000	78,500,000
1940	80,000	125,400,000
1940, last quarter rate	120,000	188,100,000
1941, estimated	160,000	250,100,000

Although the current and projected output would seem to be adequate for known requirements, there may be a major increase in demand beyond that now in sight. This could be brought about by major increase in the use of stainless steel, general substitution of chromium for

nickel steels throughout the automotive and steel industries, or sudden increase in inventories by the consumers. Such increase in demand would quickly lead to a critical situation, possible remedies for which will be explored in the following paragraphs.

Stainless steel accounts for the consumption of about 45% of the ferrochrome produced and, including that made directly from ore, accounts for approximately 50% of the ore consumption:

Table II — Distribution of FeCr in 1940

	Gross Tons 70% FeCr	
Used in stainless	40,000*	
3 to 9% Cr steels	4,000	
Low carbon, low alloy and carburizing grades	3,000	
Total usage of low carbon FeCr		47,000
Engineering and toolsteels, and irons using high carbon FeCr		33,000
Total		80,000

*Includes FeCr equivalent of 20,000 tons of ore used directly.

There is no alloy substitute for chromium in stainless steel, and the metallic substitutes which might be used for some of the applications of stainless steel comprise nickel, aluminum and zinc-base materials, which are themselves even now scarce. In making stainless steel directly from ore the ore usage is increased and the necessary ferrosilicon requires electric furnace smelting capacity. Thus, should demand arise greatly in excess of that anticipated there is only one prospect, namely, to maintain the consumption at a lower level by elimination of stainless steel in industries not essential to defense.

Architectural decorations, automobile trim and cooking utensils could all be wholly eliminated, and these items alone would reduce the stainless demand and concurrent use of ferrochromium in this field by approximately 40% (as may be gleaned from Table III). Reducing the consumption of high chromium castings and the like for furnace parts and the stainless used in the chemical industries, ordnance work and similar applications would not

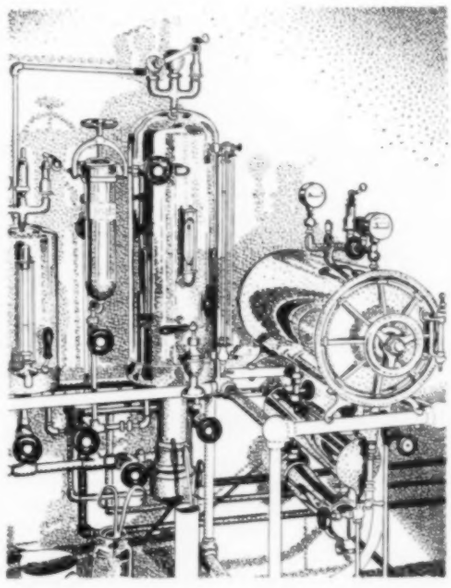


Table III — Estimated Distribution of FeCr in Stainless Steel in 1940

	Gross Tons of FeCr	Proportion
Product		
Strip	16,500	41.3%
Sheet	7,800	19.6
Other rolled products	12,200	30.4
Forgings and castings	3,500	8.7
Total	40,000*	100.0%
Industry		
Automotive	17,000	42.5%
Household	1,500	3.7
Building construction	700	1.7
Food and chemical	7,100	17.8
Transportation and machinery	7,100	17.8
Others	6,600	16.5
Total	40,000*	100.0%

*Includes equivalent of 20,000 tons of ore used directly.

appear to be necessary even under extreme conditions, but the possible use in some applications in the chemical industries of non-metallic products such as plastics and carbon forms should not be overlooked in an emergency. The use of clad steel to a greater degree than at present could save chromium in some applications and should be thoroughly investigated.

Less than 5% of the ferrochromium finds its way into tubing, bar and plate of the 4 to 9% chromium variety which is essential to the oil industry and is used in similar production applications which might be considered essential. The proportionate amount of ferrochromium involved is small and no attempt should be made to substitute in this case. The use of lower amounts of chromium and higher amounts of silicon in the 4 to 6% chromium grade has been mentioned. This would result in a net gain in the chrome ore situation, with a very small gain in the smelting capacity due to the increased load on the ferrosilicon smelting capacity. Moreover, an added burden would be put on the steel mills and fabricator as the lower chromium, higher silicon material does not lend itself as well to fabri-

(Text continues on page 680)

Properties of the Principal Cr-Fe Alloys

	2% Cr	5% Cr		9% Cr	12% Cr		Cutlery		17% Cr		27% Cr	
Chemical composition												
Chromium	1.75 to 2.25	4 to 6		8 to 10	12 to 14		13 to 14		16 to 18		25 to 30	
Nickel	(0.5 Mo)	—		(1.5 Mo)	—		—		—		—	
Si and Mn (max.)	0.50	0.50		0.50	0.50		0.55		0.50		0.50	
Carbon	0.15 max.	0.10 to 0.20		0.15 max.	0.10 max.		0.30 to 0.40		0.10±		0.10±	
Specific gravity												
Lb. per cu. in.	—	0.280		0.282	0.276		0.278		0.273		0.270	
(Mild steel = 1.00)	—	0.99		1.00	0.97		0.98		0.96		0.95	
Electrical resistance at 70°F												
Microhms per cm^3	—	—		—	57		60		59		67	
(Mild steel = 1.00)	—	—		—	5.2		5.5		5.4		6.1	
Melting range, °F.												
Top	—	2800		—	2790		2750		2750		2750	
Bottom	—	2760		—	2750		2580		2710		2710	
Structure (normal)	Pearlitic	Pearlitic		Martensitic	Martensitic or Ferritic		Martensitic		Ferritic		Ferritic	
Magnetism												
Ferromagnetic	Yes	Yes		—	Yes		Yes		Yes		Yes	
Permeability: As annealed	—	—		—	—		—		—		—	
Permeability: Cold worked 10%	—	—		—	—		—		—		—	
Specific heat												
C.g.s. units, 0 to 100°C.	—	0.11		—	0.11		0.117		0.11		0.11	
(Mild steel = 1.00)	—	1.0		—	1.0		1.1		1.0		1.0	
Thermal conductivity												
*C.g.s. units at 100°C.	—	0.0874		—	0.0595		0.05		0.0583		0.0500	
(Mild steel = 1.00)	—	0.73		—	0.50		0.42		0.49		0.42	
C.g.s. units at 500°C.	—	0.0803		—	0.0686		—		0.0624		0.0583	
Thermal expansion per °F. x 1,000,000												
From 32 to 212°F.	—	6.1		6.29	6.1		5.7		6.0		5.9	
(Mild steel = 1.00)	—	0.93		0.95	0.93		0.87		0.91		0.90	
From 32 to 932°F.	—	7.2		7.00	6.7		6.6		6.7		6.3	
Mechanical Properties at Room Temperature	**Annealed**	**Annealed**	**†Heat Treated**	**Annealed**	**Annealed**	**†Heat Treated**	**Annealed**	**††Heat Treated**	**Annealed**	**Cold Worked (Wire)**	**Annealed**	**Cold Worked (Wire)**
Ultimate strength, 1000 psi.	60 to 70	66	115	75 to 87	65	125	100	230 to 260	75	100 to 190	75 to 95	85 to 175
Yield point, 1000 psi.	30 to 45	27	103	35 to 45	35	100	65	200 to 220	40	—	50 to 60	55 to 155
Elastic modulus, 10^6 psi.	—	—	—	—	28	—	—	—	29	—	—	—
Elongation, % in 2 in.	40 to 30	38	20	40 to 30	35	20	27	8 to 2	27	—	30 to 20	—
in 10 in.	—	—	—	—	—	—	—	—	—	25 to 2	—	25 to 2
Reduction of area, %	—	76	66	—	65	60	59	20 to 2	55	40 to 20	60 to 50	55 to 25
Impact, ft-lb., Charpy	35 to 65	—	—	35 to 60	—	75	—	—	—	—	—	—
Izod	—	80	75	—	80	—	—	—	8 to 25	—	—	—
Fatigue endurance limit, 1000 psi.	—	—	—	—	—	—	—	—	48	—	50	—
Corresponding ultimate strength									76		78	
Hardness, Brinell	130 to 160	136	250	145 to 180	140	230	170	480	175	185 to 270	160 to 190	150 to 250
Rockwell	—	B-75	C-24	—	B-76	C-22	—	C-56	B-85	B-90 to 105	B-80 to 90	C-0 to 25
Erichsen value, mm.	—	—	—	—	—	—	—	—	7 to 9	—	—	—
Stress in psi. causing 1% "creep" in 10,000 hr. at 1000°F.	11,400	7,000		11,600	13,000				8,500		—	
1100	5,650	—		6,950	5,200				5,200		—	
1200	3,150	—		2,300	2,100				2,100		1,600	
1350	—	—		—	1,400				1,200		400	
Scaling temp., °F.		1200		1200	1300		1750		1550		2100	
Initial forging temp., °F.		2100		—	2100		2000		2000		2200	
Finishing temp., °F.		About 1400		—	max. 1450		1700		max. 1400		max. 1400 to 1450	
Annealing treatment		Furnace cool from 1580°F.		—	Prolonged heating at 1250 to 1350°F.		1575 to 1625°F.		**		1 hr. or more at 1450°F. and quench	

* Thermal conductivity is measured as calories per sq. cm. per sec. per °C. per cm.
† Quenched and drawn at 1100°F. †† Oil Quenched from 1850°F. and drawn.
** Small cold reduction, followed by anneal at 1400°F. and quench

Properties of the Principal Cr-Ni-Fe Alloys

	18-8			18-12		25-12		25-20	18-26
Chemical composition									
Chromium	17 to 19	Modifi-		17 to 19		22 to 28		24 to 26	17.5 to 19.5
Nickel	8 to 10	cation		11 to 12.5		12 to 16		19 to 21	25 to 26
Si and Mn (max.)	0.50	with		0.50		—		1.0 & 0.75	3.0 Si max.
Carbon	0.10	titanium		0.10		0.15±		0.15 max.	0.20 max.
Specific gravity									
Lb. per cu. in.	0.286	0.285		0.287		0.283		0.285	0.280
(Mild steel = 1.00)	1.01	1.01		1.02		1.0		1.01	0.99
Electrical resistance at 70°F.									
Microhms per cm.³	70*	71		73		78		90±	102
(Mild steel = 1.00)	6.4	6.5		6.7		7.1		—	9.3
Melting range, °F.									
Top	2590	2590		—		2570		2600	—
Bottom	2550	2550		—		2530		2550	—
Structure	Austenitic	Austenitic		Austenitic		Austenitic		Austenitic	
Magnetism									
Ferromagnetic	—	—		—		—		Trace	—
Permeability: As annealed	1.003	1.003		1.003		1.003		1.003	—
Permeability: Cold worked 10%	1.10	—		1.006		1.003		—	—
Specific heat									
C.g.s. units, 0 to 100°C.	0.12	0.12		0.12		0.12		—	—
(Mild steel = 1.00)	1.1	1.1		1.1		1.1		—	—
Thermal conductivity									
**C.g.s. units at 100°C.	0.0390	0.0385		0.0380		0.03 to 0.04		0.03 to 0.04	—
(Mild steel = 1.00)	0.33	0.32		0.32		0.25 to 0.35		0.25 to 0.35	—
C.g.s. units at 500°C.	0.0515	0.0528		0.0520		—		—	—
Thermal expansion per °F. x 1,000,000									
From 32 to 212°F.	9.6	9.3		9.9		8.3		8.8	8.8
(Mild steel = 1.00)	1.45	1.40		1.50		1.26		1.33	1.33
From 32 to 932°F.	10.2	10.3		10.8		9.6		9.4	9.3
Mechanical Properties at Room Temperature	Annealed	Cold Worked (Wire)	†Stabilized	Annealed	Cold Worked (Wire)	Annealed	Cold Worked (Wire)	Annealed	Annealed
Ultimate strength, 1000 psi.	80 to 95	105 to 300	80 to 95	80 to 90	105 to 275	90 to 110	110 to 270	80 to 110	90 to 110
Yield point, 1000 psi.	35 to 45	60 to 250	40 to 45	40	—	40 to 60	65 to 230	35 to 65	45 to 50
Elastic modulus, 10^6 psi.	29	—	—	—	—	—	—	—	30±
Elongation, % in 2 in.	65 to 55	—	60 to 50	60	—	50 to 35	—	60 to 45	35 to 30
in 10 in.	—	50 to 2	—	—	50 to 2	—	35 to 2	—	—
Reduction of area, %	65 to 55	65 to 30	65 to 55	65	65 to 30	60 to 45	55 to 20	—	45 to 35
Impact, ft-lb.; Charpy	80	—	77	—	—	—	—	40 to 80	—
Izod	75 to 110	—	—	—	—	—	—	—	50 to 90
Fatigue endurance limit, 1000 psi.	35	94	48	—	—	52	—	—	—
Corresponding ultimate strength	90	150	90	—	—	110	—	—	—
Hardness, Brinell	135 to 185	170 to 460	135 to 185	135 to 165	170 to 380	150 to 185	170 to 325	130 to 190	160 to 185
Rockwell	B-75 to 90	C-5 to 47	B-75 to 90	B-75 to 85	C-5 to 40	B-80 to 90	C-5 to 40	—	—
Erichsen value, mm.	11 to 14	—	—	—	—	—	—	—	—
Stress in psi. causing 1% "creep" in 10,000 hr. at									
1000°F.	17,000							—	7,000
1200	7,000							7,400	—
1350	3,000							3,300	—
1500	850							1,100	—
1600	—							—	1,900
Scaling temp., °F.	1650		1650	1650		2100		2000	1650
Initial forging temp., °F.	2200		—	As for 18-8		2200 to 2300		—	1950
Finishing temp., °F.	Not under 1600 to 1700		—	As for 18-8		Not under 1600 to 1700		—	—
Annealing treatment	Heat at 1900 to 2000°F. and quench		††	As for 18-8		Heat at 2000 to 2150°F. and quench		—	As for 18-8

* Electrical resistance of cold worked 18-8 ranges from 70 to 82 microhms per cm. cube

** Thermal conductivity is measured as calories per sq. cm. per sec. per °C. per cm.

† Small cold reduction, followed by anneal at 1400°F. and quench

†† Final heat treatment must consist of 2 to 4 hr. soak at 1550°F.

cation, and the net savings would be further reduced by decreased service life and need for more replacements.

A small amount of chromium in the form of ferrochrome now finds its way into 3% chromium-molybdenum steels used for special forgings, armor and the like. No attempt should be made to curtail in this application because of its strategic character. In addition, a few per cent of the total ferrochromium is found in the special low alloy steels, carburizing steels and armor plate requiring low carbon ferrochromium. This could be eliminated by substitution of manganese or nickel, but the substitute would not have all the desired properties of the chromium steels, and in view of the small quantities involved as well as the strategic nature of the substitutes an effort in this direction hardly seems worth while.

Slightly more than 40% of the total ferrochrome produced is found in the engineering and toolsteels and cast irons. In most instances nickel and manganese steels could be used as substitutes, although this would in a number of instances involve redesign and special testing as well as reduced service life. Moreover, manganese and nickel both being strategic materials, there seems to be little point in considering such substitutes. Combinations of molybdenum, vanadium and silicon might be substituted for some of the chromium in these steels, and provided these alloys were sufficiently available it is probable that a reduction of 20% of the chromium consumed could be made in this field, although here again individual conditions would have to be studied and there would be a certain amount of delay, redesign and loss of service functioning involved.

Certain special uses of chromium have not been mentioned above because the amounts involved are so small. Chromium in high speed steels has been lumped with the engineering steels because the amount, some 1500 gross tons of ferrochromium, is too small to warrant special consideration. However, it should be emphasized that there is no substitute for this highly important use. Chromium for chromium plating and chromium in the form of chromium metal used in the non-ferrous industry both come from ores which are classed as "chemical", and the amounts involved are small.

Chromium from special iron ores such as Mayari, while useful as a substitute in a small way, could not be an important factor.

Again, exothermic briquets have been used. The high carbon variety is a briquetted mixture containing, among other things, ferrochromium and sodium nitrate. The low carbon variety is a similar mixture with carbon but containing calcium chromate. There is a question whether a higher overall chromium economy can be achieved by either of these.

● ● ●

At a recent meeting held at the General Motors Proving Ground, where the 1942 models were shown to dealers, a number of talks were given by general officers on different aspects of the automobile industry. The subject of "Substitute Metals" was discussed by the head of the metallurgy department of the Research Laboratories, and he touched upon the changes necessary in the bright work. This represents pretty generally the case of stainless steel used for decorative purposes — a use estimated to absorb half of the "normal" make of stainless steels.

Substitutes for Decorative Work

By A. L. Boegehold

STEELS containing 12 to 14% chromium, 16 to 18% chromium, or a combination of 18% chromium and 8% nickel, have been widely used for body molding and trim. The stringency of nickel and chromium has required the elimination of this form of decoration, but this should cause no hardship from the standpoint of operating the car either as to its durability or its performance.

The use of copper, nickel and chromium for plating comes under the same category. Plating can be eliminated, even though it may have an important effect on appearance.

Present plating practice consists of first depositing about a 0.0003-in. layer of copper on the steel or other metallic base, and over this is plated about 0.0007 in. of nickel, and finally ten millionths of an inch of chromium. It has been found that nickel could be saved on exterior work by reducing it to 0.0003 or 0.0002 in. if the copper could be increased to 0.0007 in., without sacrificing protection against corrosion. For parts inside the body the nickel could be eliminated entirely, so that only copper and chromium would be used. If the amount of copper allotted by priorities is not sufficient, then plating for decorative purposes may have to be eliminated.

Valve Steels — There is no adequate substitute for chromium in steels used to resist heat

The A-B-C of Corrosion and Heat Resisting Steels

Arrangement due to F. R. Palmer. Adapted from The Book of Stainless Steels, Second Edition

	Group A (Martensitic)	Group B (Ferritic)	Group C (Austenitic)
Chemical Analysis	Chromium less than about 16%; carbon in balance but ordinarily less than about 0.40%. May contain a little tungsten, nickel, silicon, columbium, aluminum, and more frequently molybdenum. Magnetic.	Chromium more than about 16%; carbon quite low, but can increase as chromium goes up. May contain small percentages of copper, nickel, silicon, molybdenum, tungsten, nitrogen. This group is magnetic.	Contains enough nickel to make steel austenitic and non-magnetic. They usually contain twice as much chromium as nickel or vice versa; total alloy content at least 24%. Carbon quite low. (Manganese sometimes substituted for nickel, in part.)
Heat Treatment	Respond to hardening and tempering. Resulting physical properties depend on chemical analysis (principally carbon content).	Harden hardly at all. 18% Cr toughened by long anneal at more than 1400° F., and air cooling. Avoid decarburizing the skin. 25% chromium gets best strength and toughness by rapid cooling from 1650°.	Do not respond to hardening by heat treatment. Must be rapidly cooled from soaking heat at 1900 to 2150° F. to retain austenitic structure free of carbides. (Brinell 140 to 170).
Toughness	Are structurally dependable after heat treatment; not brittle in notched sections or under impact. Suffer some loss in impact after tempering in 800 to 1100° F. range.	Laminated structure, from coarse ferrite in ingot, causes low impact values, but proper rolling and heating gives adequate toughness in rods, bars, and sheets. Structure is refined by alloying with nitrogen.	Extremely tough at all temperatures down to liquid air. Dependable against shock except when corroded at grain boundaries (a preventable condition).
Grain Growth and Structural Changes at High Temperatures	Not subject to excessive grain growth. Thoroughly dependable for supporting any load or shock within their carrying capacity up to 1400° F. Brittleness in plain chromium steels when cooled after long heating is avoided by addition of molybdenum.	The chromium-irons low in carbon and those high in silicon or aluminum (when cold worked) are subject to excessive grain growth, especially above 1900° F. Grain growth reduced by nitrogen. Long service at 800 to 950° F. makes them brittle when cold, although they are not brittle at working temperatures.	Alloys near the austenite-martensite border line tend to precipitate carbides at grain boundaries during service at 800 to 1600° F., losing some toughness and becoming susceptible to intergranular attack. This is controlled by very low carbon, by titanium or columbium, by increasing the chromium and nickel, or by prior "stabilization."
Strength at Elevated Temperatures	Much better than straight carbon steel for temperatures up to 1000 or 1200° F. Retain tensile properties up to 750° F.	Heat resisting varieties quite tough at temperatures up to 1600° F. Inferior to Group C in creep resistance.	Have high creep strength up to 1200° F. which is enhanced by tungsten or molybdenum. Toughness impaired in non-stabilized alloys by service at 800 to 1600° F.
Hot Working Qualities	Readily forged, pierced, or rolled at 2000 to 1700° F. Preheat and soak stock at 1600° F. Plain chromium alloys air harden on cooling.	May be forged, rolled, or pierced. Should be heated quickly. Forge from 2200° F. down to 1750° F. On last heat continue cold working to 1400° F. to refine grain. Alloys do not air harden.	May be forged, rolled, or pierced. Preheat and soak at 1600° F., heat quickly to 2200° F., forge down to 1850° F. Hot short range: 1800 to 1300° F. Alloys do not air harden.
Cold Working Qualities	Low carbon varieties can be easily cold drawn into wire, cold rolled, bent, formed, upset, coined, and deep drawn.	Can be cold drawn into wire, cold rolled, bent, formed, upset, coined, and deep drawn, especially when warm (300 to 500° F.).	Can be cold drawn into wire, cold rolled, bent, formed, upset, coined, and deep drawn. Work-harden twice as rapidly as Groups A and B.
Machinability	Machine satisfactorily with properly designed tools when heat treated to 200 to 250 Brinell. Free-cutting grade contains complex sulphides or selenium.	Machine satisfactorily with properly designed tools. Cold working and high sulphur or selenium improve machinability.	Most difficult of all even with super high speed and carbon tools. Use sharp tools having greater top rake than usual, and cut continually. Free-cutting grade contains sulphur or selenium and phosphorus.
Riveting	Make excellent cold rivets. Air hardening, high chromium steels not recommended for hot rivets driven above 1500° F.	Extra precautions required to avoid brittle rivets. Conical heads should be cold upset on ground bars; rivets driven at 1425° F. into chamfered holes.	Excellent for either hot or cold rivets. Hot rivets may be driven at a high temperature (1900° F.).
Welding Properties	Preheated parts can be welded with gas, electric arc, or resistance. Anneal immediately before weld air hardens. Little grain growth. Columbium or aluminum increases ductility of welds.	Can be welded. Anneal at 1450° F. to reduce embrittlement alongside weld. Those metals subject to grain growth are brittle adjacent to the weld. Those metals not subject to grain growth yield satisfactory welds.	Can be welded with gas, electric arc, or resistance. Weld does not air harden and is very tough. Only the very low carbon or alloys stabilized with Ti, Co or Mo should be welded if article must resist corroding media.
Corrosion Resistance	Increases with chromium content; inferior to Groups B and C. Resists weather, water, steam, and mild corrodents when chromium is 11.5% or more. If carbon is relatively high, metal must be hardened and tempered (below 1000° F.).	Possess corrosion resisting properties superior to Group A; increases with chromium content. Especially good for nitric and other oxidizing acids.	Corrosion resistance depends largely upon total alloy content. Markedly improved by molybdenum. Resists nearly all corrodents measurably better than Groups A and B; especially good for organic acids. Severe pitting may occur in stagnant chloride solutions.
Scale Resistance	Increases with chromium content. Generally useful for continuous temperatures up to 1200° F., and in some services up to 1500° F.	Superior to Group A, especially when chromium is above 25%; then resist reducing atmospheres up to 2100° F., resist oxidizing gases up to melting points, and sulphur gases up to 1800° F.	Excellent where combination of high temperature and corrosion is to be met. High chromium, low nickel alloys required to resist sulphurous gases. Addition of 2 to 3% silicon markedly improves scale resistance.

corrosion such as occurs in exhaust valves. Three steels are in use in General Motors cars, namely 24% Cr and 5% Ni, 22% Cr and 2% Ni, and 21% Cr and 12% Ni. Conditions in modern automobile engines are such that the earlier valve steels such as "silcrome" containing 8.5% chromium and 3.5% silicon are no longer satisfactory.

The Editor recently discovered that large quantities of a hardenable stainless steel containing less chromium and nickel than the popular 18-8 was being used by the Glen L. Martin Co. for various aircraft details, so he asked the manager of the development division of Rustless Iron & Steel Corp. to write something about its properties.

16-2 Stainless Steel

By Stanley P. Watkins

ALTHOUGH stainless steel containing 16% chromium and 2% nickel has long been a popular alloy abroad, and particularly in England, it has never been used extensively in this country. Our Bureau of Aeronautics has investigated its properties extensively with the view of using it for highly stressed parts on seaplanes, such as terminal fittings and tie rods, which in the course of service will be exposed to salt spray and sea atmosphere.

There are many applications, particularly in the aircraft industry, where it is desired to have a metal equal to 18-8 or very near it in corrosion resistance, yet which can be heat treated to secure high tensile values. This includes such parts as flanges, bolts, nuts and forgings which cannot be produced in a high tensile strength from 18-8, since this alloy has an austenitic microstructure, and its hardness and strength can only be increased by severe cold work. 16-2, being a heat-treatable metal, is therefore being given more and more consideration by engineers in the aircraft industry, and undoubtedly will become in time one of our more popular alloys. Typical tensile properties of 16-2 in the annealed and heat treated condition are given below:

	ANNEALED	HARDENED AND TEMPERED
Ultimate strength, psi.	125,000	180,000
Yield at 0.2% set, psi.	100,000	130,000
Elastic limit	65,000	100,000
Elongation in 2 in.	17.5%	15.0%
Reduction of area	60.0%	50.0%
Brinell hardness	248	364

The corrosion resistance of 16-2 stainless steel is excellent and compares favorably with 18-8 when subjected to the standard Navy salt spray test. However, it is not as suitable as 18-8 for conditions involving exposure to strong acids, but is considered just as satisfactory for exposure to atmospheric conditions. 16-2 is magnetic and consequently cannot be used in close proximity to compasses.

Due to its structural nature, it cannot be annealed to as soft a state as the austenitic 18-8, and consequently it is not as suitable for cold forming operations such as upsetting, as the alloy cannot be commercially annealed to under about 230 Brinell, which is considered above the range for good cold heading. At the present time 16-2 is available in the form of billets, bars and wire. It is readily hot forged and cold drawn. It machines somewhat easier than regular 18-8, but it is not as good as 18-8 free machining.

Although the use of 16-2 for applications where 18-8 is normally used would result in considerable savings of strategic nickel, the extent to which substitutions can be made depends largely on the needs of the particular application. At the present time users are not as familiar with its properties as they are with 18-8, but considerable data are available and are being disseminated by the various producers.

In brief, 16-2 stainless steel is a useful engineering alloy, possessing corrosion resistance almost equaling that of 18-8, and being capable of heat treatment to high tensile and elastic values. For parts requiring high strength coupled with excellent corrosion resistance, 16-2 should be given consideration.

Addresses given before various chapters by the assistant director of the research laboratory, Allegheny Ludlum Steel Corp., indicated the rising importance of steels so low in chromium as to be near the conventional limit for "stainlessness", and the surprising number of their commercial varieties. Hence the following outline was prepared for presentation to the forthcoming discussion meeting on conservation.

The Various 12% Chromium Steels

By R. A. Lincoln

AS IS WELL KNOWN, stainless steels resist attack by the rapid formation of an oxide film which prevents further attack. Therefore, in

order for these alloys to resist corrosion, oxidizing conditions are necessary. With a chromium content of approximately 12% or greater, normal atmospheric conditions are sufficiently oxidizing to promote the formation of this protective film, so that with this chromium content stainless steels resist corrosion in normal atmosphere or under similar conditions. As the conditions of service become less and less oxidizing, successively higher chromium contents are necessary.

In connection with this line of thought, it might be well to mention the most important factor affecting the service obtained from stainless steels, and that is the condition of the surface. In order to obtain the best results and to allow the formation of a protective film, a clean, smooth surface free from foreign material and surface imperfections is necessary, and proper cleaning of the article or equipment can sometimes cause an alloy to give satisfactory service when it might otherwise fail. This is especially important when considering the substitution of lower chromium alloys in places where higher chromium ones have been used.

In addition to resisting corrosion at room temperature, stainless steels also resist scaling at elevated temperature. Resistance to scaling is dependent on the formation of a tightly adherent refractory oxide film. Under normal atmospheric conditions, the alloys containing 12% chromium will resist scaling at temperatures up to 1400° F.

The regular 12% chromium steel is hardenable by heat treatment; it is a "martensitic" alloy. By heating it in the proper temperature range, transformation to austenite occurs; and during subsequent cooling, varying degrees of hardness can be obtained, depending on the carbon content and the rate of cooling. Thus it is similar to common steel. During cooling the rate of transformation to martensite in these alloys is so slow that air cooling produces a degree of hardening which in plain carbon steels could only be obtained by water quenching.

Stainless steels are commonly referred to by standard type numbers and the family of 12% chromium alloys include Types 403 to 420. In normal atmosphere the 12% chromium steel will become slightly discolored by the formation of a visible film on the surface of the metal, but this film will protect the metal from any further attack. Thus the 12% chromium alloys find wide application for resisting those service conditions which are not too severe and where a slight discoloration of the exposed surface can be tolerated.

Type 410 is the basic 12% chromium alloy. It can be hardened to slightly over 400 Brinell through heat treatment, and can be softened by annealing to approximately 160 Brinell. After hardening, drawing at the proper temperatures will give any hardness within this range.

Type 403 is the regular 12% chromium alloy, whose chemical composition is held to closer limits than that specified for Type 410, and which receives special processing so that the mechanical properties best suited for turbine blades will be obtained.

Type 405 is a 12% chromium alloy which is practically non-hardening by heat treatment. The addition of a small quantity of aluminum, as well as a low carbon content, produces an alloy which is permanently ferritic in microstructure; it does not transform into austenite when heated to elevated temperatures and therefore is not hardenable by heat treatment. This alloy is used in applications where the metal has to be heated during fabrication into the range from which the regular 12% chromium steels harden. However, Type 405 is subject to the same disadvantages that the higher chromium, ferritic, non-hardening alloys are subject to: Heating to excessively high temperatures results in grain growth, and this large grain is accompanied by lowered toughness, although the alloy is soft to the Brinell test. Weld metal of this composition is coarse grained and lacks toughness in spite of the fact that it is soft. Welding can best be done with an austenitic welding rod, provided the structure is not to be used at elevated temperatures.

Type 406 is a 12% chromium alloy to which approximately 4% aluminum has been added, with the result that the alloy has an extremely high electrical resistance. The aluminum has also raised the temperature to which scaling in normal atmosphere will be resisted. This alloy finds use as the winding in rheostats and as inexpensive windings or resistors for electric furnaces which do not have to operate at too high a temperature.

Type 416 is the regular 12% chromium alloy to which certain elements have been added to improve machinability. Its properties are not very different from those of Type 410, with the exception of cutting ease, and it is widely used in such parts as valve stems, machined on automatic machines.

Type 418 is a 12% chromium alloy to which

approximately 3% tungsten has been added in order to improve the high temperature properties. Tungsten increases the creep strength and at the same time increases its resistance to tempering. As an example of this latter condition, Type 410 (the basic 12% Cr stainless steel) can be hardened to approximately 300 Brinell and heated indefinitely in the vicinity of 700° F. without losing any of this hardness through tempering. However, if 700° F. is exceeded for a long period of time, the hardness will fall off gradually; long heating in the vicinity of 900° F. has lowered the hardness to below 180 Brinell. However, the addition of 3% tungsten to 12% chromium steels results in Type 418, an alloy which, when hardened to 300 Brinell, can be heated indefinitely in the vicinity of 900° F. without softening. This is of importance during service as stems in valves operating in superheated steam. The addition of tungsten to the 12% chromium alloy also lowers the hardenability of the alloy slightly so that in order to obtain equivalent hardening it is necessary to have slightly higher carbon content than Type 410. Thus, in order to insure a hardness of 300 Brinell, carbon in the range of 0.12 to 0.15% should be specified.

Type 420 stainless steel covers the 12% chromium steel where high hardness is desired. The composition usually furnished under this specification is approximately 0.35% carbon, 12.5% chromium, which is known also as the regular grade of cutlery steel. It can be hardened by heat treatment to Rockwell C-55 and has its maximum corrosion resistance in the hardened and polished condition.

The manufacture of powder, of various acids and of a host of other chemical products is best carried out in stainless steel apparatus, generally fabricated by welding. Sometimes a stainless steel liner is inserted inside a heavy steel vessel. Efforts have been made to make stainless-clad steel and to apply it to such uses. Welding the joints is an obvious difficulty, but one to which considerable attention has been paid, and which, with good technique, is feasible. The difficulty has been that but two or three makers have tackled the problem of producing stainless-clad in earnest, whereas there are many makers of solid stainless, and the engineering development and sales effort have been overwhelmingly on the side of the solid stock. Generally speaking, in normal times, the cost of cladding and the cost of welding the clad material have made the final product almost as expensive as the solid stock. However, from the conservation point of view, it seems that in any sanitary or chemical application, particularly those in which only one face needs to be corrosion resistant, stainless-clad ought to be used instead of solid stainless if the design can possibly be engineered to permit. Since there are so many practicable metallurgical ways of making bi-metals, it is apropos to reprint a systematic classification from METAL PROGRESS' 1940 Annual Reference Issue by the research engineer for A. O. Smith Corp.

Composite Steel Products

By Merrill A. Scheil

A NUMBER of processes have been developed to manufacture composite materials made up of a mild steel base which furnishes the strength to meet design requirements, effectively clad with a moderate thickness of corrosion resistant metal. Each process may be identified by its method of effecting the bond between the two metals. A classification of the commercially important composite metals, with respect to the method of effecting the bond, is listed below. The list makes no pretense to cover the entire field of metals, ferrous and non-ferrous, or all the possibilities of making joints or unions, but is thought to include the important variations of composite steels.

A — Casting On

A-1. Composite toolsteel stock is made by casting a high carbon steel around a mild steel ingot prior to rolling, thus effectively bonding a cutting edge or wear resisting surface to the base.

Composite steels — Crucible Steel Co.

A-2. Copper clad stock is made by casting copper around a steel bar. The composite bar is rolled to rod and drawn to wire or a composite ingot rolled to sheet or plate.

Copper Clad wire, rod — Copperweld Steel Co.
Sheet and Plate — Clad Metals Industries.
— Republic Steel Corp.

A-3. A stainless clad steel is made by casting mild steel around an assembly of stainless steel plates separated by insulating material and edge welded. The assembly is rolled and separated.

Ingaclad — Ingersoll Steel & Disc Div. of Borg-Warner Corp.

A-4. Steel-backed bearings are made by continuous casting of a layer of babbitt or other bearing metal on a tinned strip of steel, or by centrifugal casting inside a tube.

Continuous — Cleveland Graphite Bronze Co.
Centrifugal — Wilcox-Rich Co. and others.

Engineering Properties of Monel

Data from
International Nickel Co., Inc.

Monel is a solid solution of nickel and copper approximately 67:30, with added elements to control certain properties. Typical compositions are as shown at right:

Product	Ni	Cu	Fe	Mn	Si	C	Al	S
Wrought; Regular	67	30	1.4	1.0	0.1	0.15	....	(Note)
"K" (heat treatable)	66	29	0.9	0.4	0.50	0.15	2.75	0.005
Cast; Regular	67	29	1.5	0.9	1.25	0.3	....	.....
"H" (high strength)	65	29.5	1.5	0.9	3.0	0.1	....	.....
"S" (non-galling)	63	30	2.0	0.9	4.0	0.1	....	.....

(Note) A high sulphur variety called "R" Monel is free machining.

Properties of Monel Castings

Property	Regular	H Monel	S Monel
Tensile strength (1000 psi.)	65 to 90	90 to 115	110 to 145
Yield (1000 psi. for 0.5% extension)	32.5 to 40	45 to 75	80 to 115
Elongation (% in 2 in.)	45 to 25	20 to 10	4 to 1
Izod impact, ft-lb.	80 to 65	45 to 35	5 to 1
Brinell hardness	125 to 150	175 to 250	275 to 375
Rockwell number	55 to 75-B	.....	<32-C

Temperature for slight oxidation ..... 570° F.
Annealing range (standard monel) ....1400 to 1800° F.
Forging range (standard monel) .....2150 to 1600° F.
Pouring range for castings .....2700 to 2850° F.

Cold-Rolled Sheet and Strip

Temper	Sheet		Strip		Approx. Tensile Strength
	Shore	Rockwell B	Shore	Rockwell B	
Dead soft	16 max.	60 max.	16 max.	60 max.	70,000
Soft	.....	.....	17 to 18	61 to 68	75,000
Soft skin-hard	17 to 20	61 to 73	.....	.....	.....
Skin hard	.....	.....	19 to 20	69 to 73	77,500
Quarter hard	21 to 24	74 to 82	21 to 24	74 to 82	80,000
Half hard	25 to 30	83 to 89	25 to 30	83 to 89	90,000
Three quarter	31 to 35	90 to 93	31 to 35	90 to 93	100,000
Hard	36 min.	94 min.	36 to 40	94 to 97	110,000
Full hard (strip)	.....	.....	41 min.	98 min.	120,000

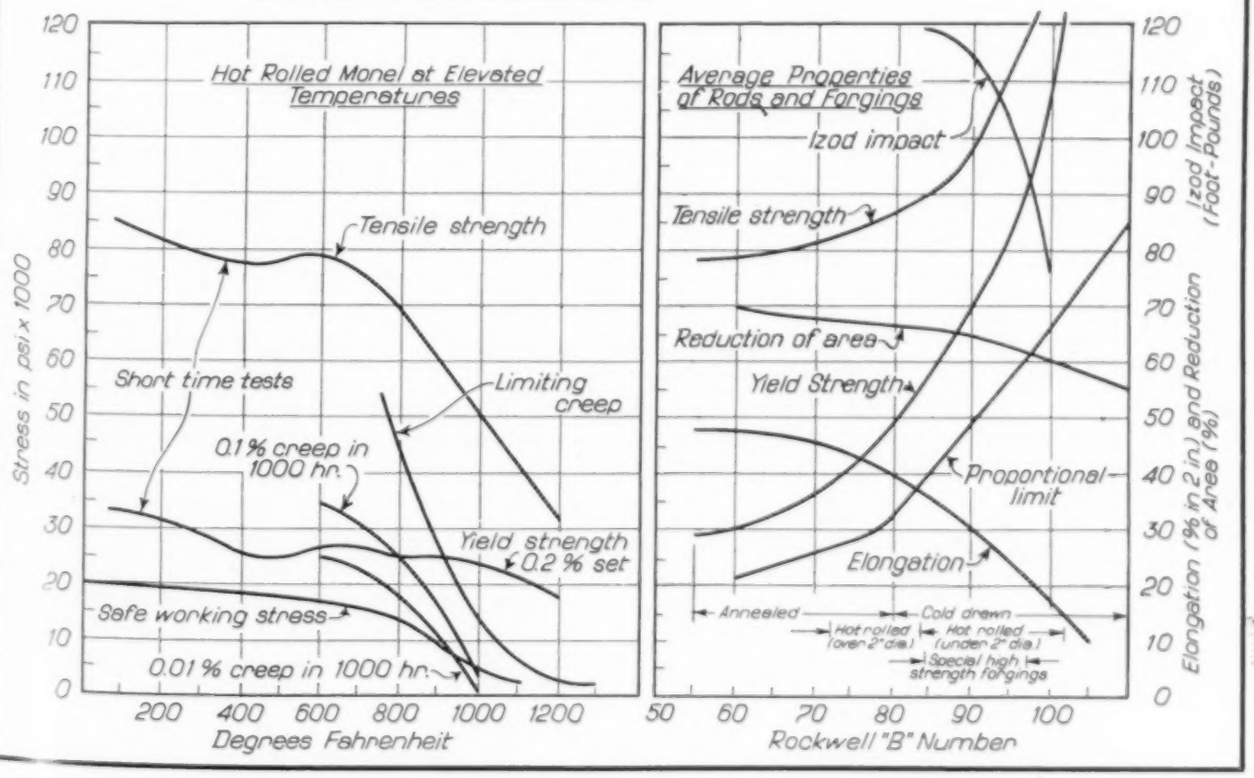
Physical Constants of Wrought Monel

Specific gravity 8.84
Density, lb. per cu.in. 0.319
Melting range
degrees F. .....2370 to 2460
degrees C. .....1300 to 1350
Specific heat at (80° to 212° F.)
(27° to 100° C.) 0.127
Heat expansion coefficient
at 80° to 212° F., per °F.....0.0000078
at 25° to 100° C., per °C.....0.000014
Thermal conductivity
at 80° to 212° F., B.t.u./sq.ft./hr./° F./in. 180
at zero to 100° C., cal./sq.cm./sec./° C./cm. 0.06
Electrical resistivity
at 32° F., ohms/circ.mil.ft. 290
at 0° C., microhms/cm.³ 48.2
Temperature coefficient of electrical resistivity
per ° F. 0.0011
per ° C. 0.0019
Modulus of elasticity
in tension, psi. 26,000,000
in torsion, psi. 9,500,000
Poisson's ratio 0.32

Mechanical Properties of K Monel

Condition	Ultimate*	Yield (0.5% Set)*	Elongation	Reduction	Brinell
Soft, quenched from 1450° F.	<120	<60	>40	>50	<200
Reheated to 1000° F.	120 to 140	80 to 100	>30	>35	225 to 275
Reheated to 1100° F.	140 to 160	100 to 120	>20	>25	275 to 325
Cold worked and reheated to 1100° F.	>160	>120	>15	>20	>325†

*In 1000 psi. †Machined only with difficulty.



B — Pressure Welding

B-1. Non-ferrous metals and alloys are pressure welded to steel backing by rolling together at a high temperature.

Nickel and Monel clad — Lukens Steel Co.
Everdur clad — Republic Steel Corp.
Copper clad — Various.
Silver clad — Handy & Harman.

B-2. A pressure welded bond between stainless alloys and mild steel is obtained by inserting an ingot iron sheet between the alloy and the mild steel and rolling the assembly to gage.

Plykrome — Plykrome Corp.

B-3. A pressure welded bond between stainless alloys, toolsteels, and alloy steels and mild steel is obtained by rolling together a stainless alloy plate electroplated with pure iron on the side in contact with the steel and a steel plate.

Silver-Ply Clad Steel — Latrobe Electric Steel Co. — Jessop Steel Co.

C — Fusion Welding

C-1. Overlapping beads of weld metal are deposited on the surface of a steel slab by oxy-acetylene, atomic hydrogen, or electric arc welding. The surfaced slab may be rolled to plate and retains the alloy deposit on the deposited surface, or used as welded.

Kelkalloy — M. W. Kellog Co.
Stelliting and hard surfacing — Open.
Lead linings in steel drums, etc. — Lead Lined Iron Pipe Co.

C-2. A fusion bonded deposit of a secondary metal is fused with a carbon arc from a mixture of metallic forming material to the surface of a steel slab. The secondary metal is retained as a cladding on the plate or sheet after rolling to gage.

Kinkead's process.

C-3. A combination fusion and casting process employs a soft steel slab as one side of a narrow mold. An ingot of desired composition, bonded to the slab, is built up in the mold. An automatic welding head which makes a traverse in the mold supplies the metallic forming material. The composite slab thus formed is then rolled to gage.

Pluramelt — Allegheny Ludlum Steel Corp.

D — Electric Resistance Welding

D-1. A composite plate is fabricated by electric resistance spot welding a finish rolled alloy sheet to a rolled steel plate. No additional rolling of the composite is required. Two variations of this process include:

Resistance spot welds on close centers — A. O. Smith Corp.
Overlapping spots — Babcock & Wilcox Co.

D-2. Butt weld two slabs over the entire surface and roll to gage.

Various bi-metals — W. M. Chace Co.

Mr. Boegehold, on page 680, mentions the great difficulty, if not impossibility of substituting for nickel but especially chromium in exhaust valves which must withstand the blast of hot engine gases. A fuller discussion of the problem as it applies to electrical resistance alloys, such as 60% nickel, 25% iron and 15% chromium, or 70% nickel, 10% iron and 20% chromium is given in an early report on nickel (dated March 15, 1941) of the National Academy of Sciences' Advisory Committee to OPM on Metals Conservation and Substitution.

Heat Resisting Alloys and Electrical Resistors

By Advisory Committee to OPM on Metals

MALLEABLE NICKEL and the chromium-nickel alloys for heat resistance and electrical resistors require together about 10% of the current nickel supply. A considerable portion of this nickel is used either directly for defense equipment, such as for airplane manifolds or for heat treating equipment in the steel and manufacturing industries, where it probably should be considered as essential for defense. There are certain portions of this field which might be considered, however, with respect to the possibility of nickel conservation. One is the chromium-nickel resistance wire used in the manufacture of electrical appliances, such as domestic stoves, toasters and percolators, most of which are sold for domestic use (but some are for the Government account). The only known alternative material is chromium-aluminum-iron alloy, which is not now available to the trade in the forms and quantities required, and even if it could later be made available, its use would entail extensive appliance redesign, as well as the modification of manufacturing methods suitable for the alternative material. The question also arises whether the aluminum required for this alloy and the larger amount of chromium required would be available when its production could be arranged.

It may be useful at this point to view the conservation problem from a different angle than that of the primary nickel consumer — namely, from the point of view of a whole industry which uses nickel products. Take the point of view of the electrical industry, for example. This industry as a whole manufactures a great diversity of products — some for defense, many for other purposes — and many

of their products contain nickel, often only small amounts but in essential forms. The amounts of nickel in electric light bulbs, in radio tubes, in transformers and other parts of telephone and telegraph circuits, in permanent magnets in electrical instruments, in thermostatic controls of all sorts — while small in individual amounts, play an important part in the functioning of the apparatus, and collectively add up to a considerable amount of nickel not readily computed. One plant alone estimates an annual nickel requirement of 500,000 lb. for a wide variety of nickel alloys and apparatus parts. Substitution can in some cases be visualized, but in others is difficult without extensive redesign.

Now these electrical products are standard products, manufactured in quantity, partly for important defense requirements and partly for industrial and even domestic use. Substitution of other materials for nickel could only be done through extensive redesign. This is sometimes practically impossible, as in the case of ferro-nickel lead-in wires for electric light bulbs. The question arises whether the amounts of nickel which can be saved in such a program of substitution — involved, detailed and expensive as it would be — justify the effort and disruption to a large industry which would be caused.

Judging from the Foreign Correspondence in METAL PROGRESS, as well as European publications, a great deal of attention has been given by German and Russian metallurgists to corrosion resistant iron alloys wherein substantial amounts of the expensive (and rare) chromium and nickel are replaced by the much more available manganese, copper, aluminum and silicon. Of these, manganese has perhaps the most possibilities, and the following, by the well known research metallurgist of Union Carbide and Carbon Research Laboratories, outlines the situation.

Substitute Elements in Stainless

By Russell Franks

USE OF SUBSTITUTE metals like manganese, copper, aluminum and silicon in the production of stainless steels is worthy of consideration at present in view of the importance of chromium and nickel in articles needed for defense. While chromium is the basic metal used to impart stainlessness to steel, there are other metal elements (besides those discussed herein) that impart improved corrosion resistance when added to steel, but so far as is known none of these produce the same result as chromium from the standpoint of corrosion resistance and fabrication.

It is well known that several per cent of aluminum or silicon are added to certain high chromium steels for heat resisting applications. Aluminum is added to high chromium steels used for electrical resistance elements, and silicon is added to high chromium steels used for valves in internal combustion engines, but neither element greatly improves resistance to liquid corrosion, nor imparts the desired mechanical properties required in many stainless steel applications. Since aluminum alloys are widely used in aircraft construction, it is doubtful whether sufficient quantities of the metal would be available even though the required properties could be obtained.

The remaining two metals under consideration are copper and manganese. The question is whether these metals can be used as a substitute for a portion of the nickel normally present in the important austenitic 18% chromium, 8% nickel steels. Unlike nickel, sufficient percentages of copper cannot be added to the 18% chromium steels to give a steel that is fully austenitic; when much more than 1% is added, the hot working characteristics are detrimentally affected. The same is true when copper is added to the straight 18% chromium steels of the 18% chromium, 8% nickel type, and it is doubtful whether replacing 1% nickel in the 18-8's with 1% copper would prove to be a beneficial substitution.

Different results are obtained by adding manganese to steels of the 18% chromium type. Suitable percentages give a steel that is partly austenitic and partly ferritic. These steels are not so resistant to corrosion as the 18% chromium, 8% nickel steels but do possess excellent mechanical properties. They have the ability to be hot and cold worked and, in general, fabricated like the more conventional chromium-nickel steels.

A steel with a high degree of corrosion resistance is obtained by decreasing the 8% nickel content of 18-8 steels to about 4%, and adding at least 5% manganese. Like the chromium-nickel steels, one of the attributes of the chromium-nickel-manganese steel is its suitability for use in light weight, high strength construction. The properties of the steel in the cold-rolled condition, and in the cold-rolled and

Valves and Valve Seat Material

From paper by S. D. Heron, O. E. Harder and M. R. Nestor before American Society for Testing Materials

No.	Chemical Composition							Rockwell Hardness		Brinell Hardness, Hot (g)	
	C	Si	Cr	Ni	W	Mo	Other	Natural	After 1475° F. Draw	At 930° F.	At 1475° F.
						Martensitic or Pearlitic Steels					
1	0.40–0.50	3.0 –3.5	8.0 –9.0	.	.	.		C-32 to 35	C-20 to 29	169–179	16–20
2	0.35–0.45	3.9 –4.2	2.8 –3.0	.	.	.		.		.	
3	0.50	1.5	8.0	.	.	0.75		.		.	
4	0.60–0.85	1.25–2.75	19–23	1.0 –2.0	.	.		C-38	C-31	254	26
5	1.0 –1.1	1.8 –2.0	13–14	0.75–1.0	3.25–3.75	0.50–0.75					.
6	1.27–1.43	<0.65	11.5–14	<0.65	.	0.45–0.95	2.5–3.5 Co	C-55			38 at 1600°
7	0.50–0.70	.	3.0 –4.0	.	12–16	.					
8	1.0 –1.2	<0.50	12–14	<0.50	.	.					
9	0.5	0.2	11.0	1.5	.	.	0.5 Mn, 1.8 Al				
10	2.5 –3.0	1.5 –2.0	2.75–3.25	.	.	4.0 –5.0	0.6–0.8 Mn				
11	1.0	1.0	25.0	.	.	.		C-40	C-19		28
						Austenitic Steels and Nickel-Chromium-Iron Alloys					
12	0.30–0.45	2.50–3.25	17.5–20.5	7.0–9.0	.	.		C-26	C-24	142	45
13	0.20–0.30	0.70–1.00	21–22	11–12	.	.		C-20 to 27	C-18 to 22	130–180	55–78
14	0.20–0.30	2.5 –3.0	21–22	11–12	.	.		C-24	C-20	166	71
15	0.40–0.50	0.30–0.80	13–15	13–15	1.75–3.00	<0.50		C-25	C-23	162	55
16	0.40–0.50	2.75–3.25	13–15	13–15	1.75–3.00	<0.50		C-30	C-22	165	53
17	0.50	1.25	14	26	3.5	.		C-22	C-16	182	84
18	0.40–0.50	0.30–0.80	24–26	13–15		2.0 –3.0		B-94	B-94		76
19	0.95–1.20	2.0 –3.0	15–16	13–15				C-24	C-30		94
20	0.50	1.0	20	32			1.0 Mn	C-21	C-19	174	80
21	0.50–0.60	0.50	3.5	12			5.0 Mn	C-22	B-95	140	55
22	0.10	0.30	14	80			.	B-83	B-83	107	54
23	0.07	<0.75	18	8			.	B-81	B-80	74	49
						Transformation Hardening Steels					
24	0.25–0.35	2.0 –3.0	12.0–13.5	7.0–7.75				C-42	C-41	244	98
25	0.40–0.50	<1.0	23.3–24.3	4.5–5.0		2.5 –3.5		C-41	C-36	230	63
						Non-Ferrous Alloys					
26	1.25	2.7	27	.	4		65 Co			217 at 1200° F.	132 at 1600° F
27	2.0	0.9	30	.	12		54 Co			314 at 1200° F.	185 at 1600° F
28	0.20	0.30	21	Balance		0.90 Mn	0.60 Fe				
29	0.16	0.02	30.3 Cu	66.9	0.16 Al	0.90 Mn	1.6 Fe				
30			Bal. Cu	.	9.5 Al		0.5 Fe				
31			Bal. Cu	4.0–6.0	10.5–11.5 Al		4–6 Fe				
32				>99.0							

No.	Scaling Loss (a)		Corrosion Resistance in Exhaust Condensate	Relative Attack by Lead Compounds (b)			Utility and Remarks
	Oxidizing Atmosphere	Reducing Atmosphere		$PbO \cdot PbBr_2$ at 1550° F.	PbO at 1800° F.	$2\,PbO \cdot 3\,PbSO_4$ at 1800° F.	
				Martensitic or Pearlitic Steels			
1	50	140	Poor	41	100	200	Most widely used exhaust valve material.
2	160	360	Very bad	41	106	258	Cheaper variety; inferior as to burning and rusting.
3	10,000	12,000	Very bad	.	.	.	Unsatisfactory substitute for No. 1.
4	40	75	Complete	1	104	8	Rapidly replacing No. 1.
5	.	.	Very bad	.	.	.	Limited use replacing No. 6.
6	5,000	2,200	Very bad	16	136	6	Superseded No. 7 for aircraft use in early 1920's.
7	—	—	Very bad	—	—	—	High speed toolsteel; adopted in U.S. in 1911; much used in War, first valve with good hot strength.
8	19,000 (c)	19,000 (c)	Very bad	56	64	3	Cutlery stainless (modified); used in Europe for 1916-1918 aircraft.
9	.	.	(d)	26	113	5	Reputation for unreliability in automobiles.
10	18,000	17,000	.	36	240	520	Cast exhaust valve seats for passenger cars and trucks.
11	60	100	Complete	2	14	1	In experimental use.
				Austenitic Steels and Nickel-Chromium-Iron Alloys			
12	90	70	Complete	63	57	46	Wide use in automobiles for its hot strength.
13	30	60	Complete	37	43	2	Wide use in bus and truck engines.
14	50	90	Complete	48	48	17	Higher silicon than No. 13 does not improve resistance to burning.
15	2,600	1,600	(e)	20	126	26	U.S. aircraft exhaust valves; internally cooled and seat faced.
16	100	150	Complete	25	92	184	Too hard to drill; seat inserts in aluminum cylinders.
17	840	370	Complete	28	73	228	European aircraft exhaust valves.
18	50	40	(e)	12	47	0.3	Recently introduced to replace No. 15; about same in severe service; no intergranular attack by sodium.
19	140	160	Complete	.	.	.	Castings for both intake and exhaust valves on Ford motors.
20	60	40	Complete	.	.	.	Limited use, as cast, in auto, bus and truck valves.
21	11,000	11,000	(d)	.	.	.	Exhaust valve seats in European aircraft. High thermal expansion requires threaded design to remain tight.
22	60	50	Complete	40	42	254	Not used, despite interesting properties.
23	2,400	1,700	Complete	25	112	2	Not used, despite interesting properties.
				Transformation Hardening Steels			
24	2,800	2,300	Very good	49	81	24	Had limited use in autos and wide use in aircraft.
25	40	50	Complete	2	35	1	Better wear and scuffing resistance than austenitic steels; embrittled by many cycles between 1400 and 1600° F.
				Non-Ferrous Alloys			
26	20	15	Complete	0.5	4	0.5	Stellite No. 6; almost universal in U.S. for welded-on seat facings in aircraft engines.
27	50	15	Complete	72	6	1	Valve seat inserts for bus and trucks, with higher hot hardness and wear resistance than No. 26.
28	45	15 gain	Complete	71	52	197	Brightray; used in Europe for welded-on seat facings.
29	13,000	30	Very good	.	.	.	Monel; used in Europe for some exhaust valve seat inserts.
30	1,000 (f)	.	Good	100	244	243	Formerly much used as extruded valve seat inserts in aluminum cylinders.
31	.	.	Good	.	.	.	Cast and heat treated substitute for No. 30. Neither good for leaded fuels.
32	250	70	Complete	3	340	504	Commercially pure nickel; has unusually high hot corrosion resistance.

Notes: (a) Loss in mg. on ⅜x2-in. rod after 300 40-min. cycles between 1800° and 650° F. Fuel is a special kerosene with anti-knock additions, burned with 15½ lb. air per lb. for oxidizing atmosphere and 12½ lb. for reducing. Low results may be misleading.

(b) Calingaert test. Relative loss after 6 min. in molten compound.

(c) After 250 cycles.

(d) Probably very bad.

(e) Complete if not nitrided; poor when nitrided.

(f) Maximum temperature on heating cycles: 1600° F.

(g) By mutual indentation.

stress-relieved conditions, are briefly described in the following table:

ANALYSIS: Chromium 18.16%, nickel 4.59, manganese 5.55, silicon 0.41 and carbon 0.13%.

PROPERTIES	AS COLD ROLLED*	COLD ROLLED, HEATED 24 HR. AT 525° F. AND AIR COOLED
Tension		
Yield strength at 0.2% offset	147,000 psi.	159,000 psi.
Tensile strength	199,300	186,000
Elongation in 2 in.	18%	15%
Compression		
Yield strength at 0.2% offset	117,200 psi.	157,000 psi.
Buckling stress	183,200 psi.	191,100 psi.

*Tests made on 0.035-in. thick strip, cold reduced by rolling 35% in the longitudinal direction to rolling.

These values illustrate the properties that can be obtained in the austenitic type chromium-nickel-manganese steels, high in corrosion resistance, and further indicate the suitability of thin cold-rolled sections of the steel for use in aircraft construction.

Some materials can be substituted for stainless steels. For instance, lead sheets and lead pipe were once used in a much wider variety of applications. Surface treatments also have numerous and definite possibilities. Following are several brief outlines of such subjects from members of the discussion group to assemble at the forthcoming National Metal Congress and Exposition:

Calorized Steel

By B. J. Sayles
President, The Calorizing Co.

CALORIZING process results in the creation of an iron-aluminum alloy of appreciable depth on the surface of steel. The surface alloy is an integral part of the base material, not a superimposed coat. The product is resistant to high temperature oxidation and flue gas corrosion. It is highly resistant to all gaseous sulphur compounds, notably hydrogen sulphide, for which reason one of the important applications is found in tubes for oil cracking stills handling high sulphur crude. Other important applications are found in high temperature superheater tubes; containers for molten lead and salt in the heat treatment of steel; pyrometer protection tubes; boiler baffle plates; bolts for furnace construction; hanger rods for suspended roof and wall construction on furnaces and a host of other similar furnace construction materials.

Material to be calorized is packed in compound which consists of powdered aluminum, aluminum oxide and one or more energizers, and heated in rotating retorts or boxes. Originally the work was done in 6 hr. at 1700° F. Now a subsequent step is performed; the work is removed from contact with the calorizing compound and baked in air at 1800° F. for periods ranging from 12 to 48 hr. By this means the depth of iron-aluminum alloy and the aluminum concentration at the outer surface are controlled. For example, heavy walled oil still tubes are usually baked 48 hr., resulting in a surface alloy on the order of 0.030 to 0.045 in. thick with 20% to 25% aluminum at the outer face. The surface alloy is tough, exhibiting about 5% elongation, hard and able to resist abrasion such as tube cleaner wear.

Since carbon inhibits the diffusion of aluminum, it is desirable that steel for calorizing purposes have a carbon content not in excess of 0.30%. Practically any steel will calorize. A notable development is calorized carbon-molybdenum (1.50% Mo) steel which has high creep resistance up to at least 1200° F.

Calorized steel should be of particular interest and value during the current emergency since 3% of aluminum expended in the calorizing operation will, in many applications, displace 18-8 stainless steel.

There is also the interesting possibility of use for civilian needs wherever calorized steel can be satisfactorily substituted for stainless steel. Among recent promising "ersatz" samples, the Calorizing Co. has produced electric heating elements for domestic and restaurant cooking ranges of the type where the resistance wire is enclosed in a calorized carbon steel sheath tube; spark plug electrodes; flame spreaders and burner parts for domestic oil stoves; tubular type multi-flame burner pipes.

High Silicon Irons

By D. E. Jack
General Sales Manager, The Duriron Co.

ANY CHANCE of substitution of high silicon irons for the high chromium irons or the high chromium-nickel steels would be under conditions where liquid corrosion must be resisted. In this respect, there are very few corrosive conditions that a high silicon iron such as "duriron" is not equally as satisfactory as the stainless steels. In fact duriron solved most of the problems in corrosion before the advent of

stainless steel and it was the latter metal's excellent physical properties that caused stainless steels to replace duriron. When it was demonstrated that the chromium-nickel steels were satisfactory from a corrosion standpoint, chemical engineers were able to design their processes using much higher pressures and temperatures than could be used with a high silicon iron. However, there are many industries today which are using stainless steels merely due to the fact that they do not need to be so careful in the handling of the equipment, although so far as pressure, temperature, and working conditions are concerned, a high silicon-iron alloy could still be successfully used — in fact, *is* being used in a great many plants. It is in these fields that there is the greatest chance of a substitution to replace the critical supply of rare elements.

If time would permit, a great number of illustrations could be given. Many of the applications in the food processing industry, such as the manufacture of vinegar, citric acid, pineapple juice and cream of tartar could use high silicon iron in place of stainless steel with perfect satisfaction. In the chemical and metallurgical fields, any number of applications could be listed where both duriron and stainless steel are being satisfactorily used.

Silicon Impregnation

By Harry K. Ihrig
Director of Laboratories, Globe Steel Tubes Co.

THE silicon impregnation process is a method of substitution for certain parts that have previously been made from stainless steels where corrosion resistance is necessary.

Where both corrosion and wear occur on the same part, the silicon impregnated piece is especially good as a substitute — in fact, it is superior in many instances. The hard and wear-resistant nitralloy (with its relatively high aluminum content as well as a small amount of chromium) is another steel which cannot be readily obtained for non-defense purposes. This steel is used widely in the automotive industry for articles such as pump shafts and bushings. We have had much experience in replacing this material with silicon impregnated common steel with very good success.

In addition to the replacement of the alloy steels outlined above, the silicon process has another advantage from a defense standpoint. Stainless steel and other alloy steels are relatively difficult to machine; hence, machine tools are tied up for longer periods of time than they would be for the same part made from common steel. The silicon impregnation process releases these tools for other work if the parts are made from common steel and later treated for a resistant surface.

The element silicon, of course, is a very common one. Every sand pile is composed of about 50% of it, and the material used in the silicon impregnation process is amorphous silicon carbide, a by-product in the manufacture of carborundum for grinding wheels.

Therefore, it would seem that pump shafts, bushings and exhaust manifolds for the automotive industry, and chains for acid pickling baths and conveyors, are some of the articles that could be manufactured from common steel or malleable iron, and with the silicon case would be adequate substitutes for the stainless and other alloys used at present.

Silver and Platinum Linings

By Fred E. Carter
Baker & Co.

SILVER has good non-corrosive properties and is particularly valuable in combating chlorine gas, alkalis and organic acids. Much silver equipment has been used in the food, chlorine and other industries. Although the metal is not very expensive (about $5 per lb.) when larger equipment is required it is preferable to use silver clad vessels.

Platinum clad is needed for still more severe corrosive conditions. The original cost of such equipment is of course high, but the high re-sale value of the platinum greatly reduces the net cost. In addition, economy of maintenance, long life of the equipment and the guarantee of a very pure product are further factors in reducing the apparent high cost.

One important application of platinum clad equipment is in the manufacture of tubular heat exchangers where corrosive materials are being handled. These exchangers may be made with the platinum either inside or outside.

The platinum may be simply an insert, but more generally it is welded or soldered to the base metal. For larger equipment, sections of platinum clad tubing or sheet are joined together by methods developed wherein no base metal is exposed to the corrosive contents.